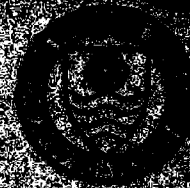END
DATE
FILMED
11-80
DTIC
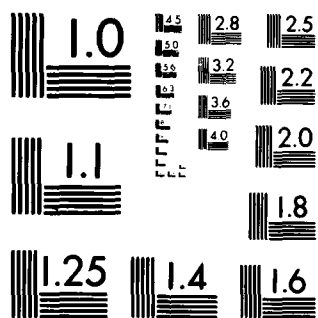
MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS

LEVEL II

STUDY FOR DEVELOPMENT OF FIBERGLASS
REINFORCED PLASTIC EARTH-COVERED
AMMUNITION STORAGE MAGAZINES

REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
Technical Report SL-80-6	AD-A090277	

4. TITLE (and Subtitle)	5. TYPE OF REPORT & PERIOD COVERED
STUDY FOR DEVELOPMENT OF FIBERGLASS REINFORCED PLASTIC EARTH-COVERED AMMUNITION STORAGE MAGAZINES	Final report. Oct 79-Jul 80.
	6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)	8. CONTRACT OR GRANT NUMBER(s)
12 79 15	Contract No. DACA 39-79-C-0012

9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
Hunt and Wales Co., Inc. New 129 Wakefield Street Reading, Massachusetts 01867	

11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE
Office, Chief of Engineers, U. S. Army Washington, D. C. 20314	September 1980
	13. NUMBER OF PAGES 73

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report)
U. S. Army Engineer Waterways Experiment Station Structures Laboratory P. O. Box 631, Vicksburg, Miss. 39180	Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Ammunition
Computerized simulation
Fiberglass
Finite element method
Munitions storage
Reinforced earth
Reinforced plastics

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A corrosion resistant fiberglass reinforced plastic (FRP), earth-covered, ammunition storage magazine was developed to provide an alternative to the steel and concrete materials presently used.

Conceptual designs were investigated, materials were selected, and a final design was developed in sufficient detail for construction of a proto-type structure. Methods for manufacture, shipping, and field erection were also established along with comparative construction cost data. (continued)

DD FORM 1473 EDITION OF 1 NOV 65 IS OBSOLETE

20. ABSTRACT (continued).

Adequacy of the developed FRP magazine design was determined by finite element analyses. Soil load distribution equations were derived and the MRI STARDYNE computer code was extensively employed with increasingly detailed structural models of the FRP magazine.

An FRP earth-covered, ammunition storage magazine is shown to be feasible and highly competitive with present construction materials. Construction of a prototype structure is recommended.

PREFACE

This report was prepared by Hunt and Wales Co., Inc. 129 Wakefield Street, Reading, MA. for the U.S. Army Engineer Waterways Experiment Station (WES) under contract number DACA 39-79-C-0012. The work was accomplished during the period from October 1979 through July 1980.

Assistance in direction and control of technical work under the contract was provided by James M. Watt Jr. of the WES, Structures Laboratory. Grateful appreciation is extended to him for his helpful technical comments and prompt resolution of questions as they arose.

Commander and Director of WES during the preparation and publication of this report was COL Nelson P. Conover, CE. Technical Director was Mr. F. R. Brown.

Accession For		
NTIS GRA&I	☒	
DDC TAB	☐	
Unannounced	☐	
Justification		
By		
Distribution/		
Availability Codes		
Dist.	Avail and/or special	
A		

3

CONTENTS

CONVERSION FACTORS, INCH-POUND TO METRIC (SI) UNITS OF MEASUREMENT

Inch-pound units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
inches	25.4	millimetres
inch-pounds	0.1129848	metre-newtons
pounds (force)	4.448222	newtons
pounds (force) per square inch	6.894757	kilonewtons per square metre

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Maintenance and construction costs of ammunition storage magazines have steadily increased. These cost increases, and recent advances in construction materials, have indicated the need to study the feasibility of fiberglass reinforced plastic (FRP) as an alternate to the steel and concrete structures that are presently used.

Fiberglass reinforced structural plastics are being successfully employed in primary structural applications such as (Reference 1) :

a) Boats and ships up to 80 ft. long.
b) Sewage tank domes up to 110 ft. diameter.
c) Tanks up to 100,000 gallon capacity.
d) Molded shell-roofed vacation houses.
e) Automobile and truck bodies.
f) Cargo containers for ocean, rail and truck shipment.
g) Large diameter buried piping.
h) Radomes and antennas.

1.2 OBJECTIVE

The objective of this study is to develop feasibility data and estabilish a design for a fiberglass-reinforced plastic (FRP) earth-covered ammunition storage magazine so as to provide designers with an added materials option.

1.3 SCOPE

The scope of the study performed may be summarized as follows:

a) Performance of a literature search and canvass of industrial and DOD organizations to document recommended practices for the design, manufacture and installation of fiberglass-reinforced plastic structures.

b) Determinations of:

- structural material, best chemical composition.
- proper fabrication and assembly procedures.
- best component fastener and waterproofing systems.
- maintenance requirements for various environmental conditions and compatability with various explosives.

- cost and other data needed to determine the feasibility of constructing such fiberglass reinforced plastic, earth-covered structures.

c) Development of several conceptual designs for an earth-covered ammunition storage magazine, using the present steel oval arch structure shown in figure 1.1 for definition of storage space requirements and soil cover depth required for blast protection.

d) Development of a final design, along with construction cost data, of the most promising concept in sufficient detail for the construction of a prototype structure.

FIGURE 1.1 PRESENT STEEL OVAL ARCH MAGAZINE CROSS SECTION
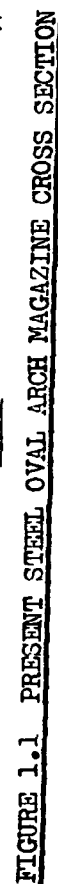
(OCE DWG. NO. 33-15-73, DATED 21 FEB. 75)

CHAPTER 2

DOCUMENTED PRACTICES

A literature search and canvass of industrial and DOD organizations was made in order to compile currently available practices for the design, manufacture and installation of fiberglass-reinforced plastic structures. During this effort, a computer literature search was conducted of the NTIS and COMPENDEX data bases.

A compilation of selected pertinent current practices and other guidance materials is listed in Table 1.

Technology and criteria provided by these documents were employed in the development of a fiberglass-reinforced plastic earth-covered ammunition storage magazine as described in later chapters of this report.

TABLE 1

COMPILATION OF PRACTICES AND OTHER GUIDANCE MATERIALS

A. Structural Plastics Design Manual FHWA-TS-79-203, U.S. Govt. Printing Office Stock No. 023-000-00495-0.

B. "Hand Lay-up Spray-up Guide"; 1979; Publication No. 5-PL-9342 Owens-Corning Fiberglass Corp. Toledo, OH.

C. James M. Duncan; "Behavior and Design of Long Span Metal Culverts"; March 1979, Pages 399-418; Journal of the Geotechnical Division, ASCE, New York, N.Y., Proceedings Paper 14429.

D. B. Jay Schrock; "Installation of Fiberglass Pipe"; Nov. 1978; Pages 835-846; Transportation Engineering Journal, ASCE, N.Y., N.Y.

E. Frank J. Heger; "Design of FRP Fluid Storage Vessels"; Nov. 1970; Journal of the Structural Div., ASCE, New York, N.Y.

F. "Frp-An Introduction to Fiberglas-Reinforced Plastics Composites" Publication No. 1-PL-6305A by Owens-Corning Fiberglas Corp. Toledo, OH.

G. "Structural Sandwich Composites", Military Handbook, MIL-HDBK-23A; Dec. 1968; Dept of Defense, Washington, DC.

H. Charles C. Huang, "Feasibility of Using Fiberglass Reinforced Plastic (FRP) Buildings for Ammunition Plants"; September 1978, Pages 1169-1194, Minutes of the Eighteenth Explosives Seminar, San Antonio, Texas, sponsored by Dept. of Defense Explosives Safety Board, Alexandria, VA.

CHAPTER 3

MATERIALS SELECTION

3.1 RECOMMENDATIONS

Isophthalic polyester resin was selected as the most suitable plastic for this application, based on collected data and the recommendations of FRP material suppliers. Considered major advantages of this resin may be listed as:

a) Adequate strength at reasonable cost.
b) Demonstrated corrosion resistance in various soils and chemical environments.
c) Wide usage and availibility.

Commercially available isophthalic polyester resins have been developed for use in a wide variety of soils encountered nationally and internationally. This resin has been used successfully for approximately 20 years in many applications of large diameter buried pipe and underground storage tanks.

Polyester resin systems are most common for general product applications. Increased mechanical properties obtainable with other resins (e.g. epoxy) are not commensurate with the higher cost of the laminate.

Fiberglass pipe is competitive with many conventional pipe materials on an as-installed basis and is considerable lower in cost than other engineering materials offering equivalent corrosion resistance and service life (Reference 2).

Only polyester resin is specified for underground storage tanks of glass fiber reinforced plastic in MIL Spec. MIL-T-5277A.

The National Bureau of Standards specification NBS-PS-15-69 has been adopted by industry to guarantee consistent quality of custom contact molded reinforced polyester process equipment.

Over 40,000 UL-listed Fiberglass (Owens Corning) fuel tanks are in service in every state from Maine to Hawaii.

Suitability of polyester resins for use in various soils and chemical environments is well-documented (Reference 3).

Balsa wood core material was selected for FRP panels of sandwich construction. Balsa was selected as the most suitable sandwich panel core material (over e.g. plastic foams, and honey-combs) for the following major reasons:

a) High available strength at minimum cost.
b) Maintenance of mechanical properties over a broad temperature range.
c) Wide usage and availability.

The forms of commercially available fiberglass reinforcement selected for the polyester resin were woven roving, mat and chopped fibers. Use of fiberglass cloth was not considered suitable because of its higher relative cost.

3.2 PROPERTIES

Typical strengths of fiberglass reinforced polyester resin laminates are listed in Table 2.

Typical strengths of Balsa FRP sandwich core material are listed in Table 3.
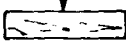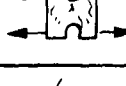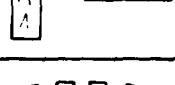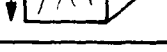
TABLE - 2

TYPICAL STRENGTH PROPERTIES OF
AROPOL 7241 TYPE LAMINATES
AT ROOM TEMPERATURE

(Provided by Ashland Chemical Co., Resins and Plastics Div., Columbus, Ohio)

	1/8"	1/4"	ASTM TEST METHOD
% Glass	24	43	
Tensile Strength, psi	10,400	20,800	D638
Tensile Modulus x 10^6, psi	1.3	1.8	D638
Tensile Elongation, %	1.2	1.6	D638
Flex Strength, psi	14,000	30,300	D790
Flex Modulus x 10^6, psi	0.7	1.5	D790
Compressive Strength, psi	--	32,000	D695

TABLE 3

PHYSICAL PROPERTIES OF BALSA FRP SANDWICH CORE

Specific gravity		.0962	.128	.176	.248
Compressive Strength (lbs./sq.in.)					
A. Parallel to grain (end grain)					
— Stress at proportional limit		500	930	1.450	2.310
— Maximum at crushing strength		750	1.380	1.910	2.950
— Modulus		330.000	480.000	768.000	1164.000
B. Perpendicular to grain (flat grain)					
— Stress at proportional limit					
High strength value		84	115	144	198
Low strength value		50	75	100	145
— Modulus					
High strength value		16.000	24.400	37.000	55.000
Low strength value		5.100	8.260	13.000	19.900
Bending Strength (lbs./sq. in.)					
Static bending					
— Stress at proportional limit		825	1.250	1.725	2.535
— Modulus of rupture		1.375	2.200	3.050	4.525
— Modulus of elasticity		280.000	425.000	625.000	925.000
Tensile Strength (lbs./sq. in.)					
A. Parallel to grain (end grain)					
— Maximum		1.375	1.850	3.050	4.525
B. Perpendicular to grain (flat grain)					
— Maximum: high strength value		112	140	170	223
low strength value		72	95	118	156
Toughness (inch pound per specimen)					
High strength value		125	200	310	475
Low strength value		120	180	267	400
Shear (lbs./sq. in.)					
High strength value		180	265	360	522
Low strength value		158	235	298	425
Modulus		14.450	21.400	31.800	
Hardness (lbs.)					
Load required to embed a .444" ball to one half its diameter					
A. Parallel to grain (end grain)		102	170	250	386
B. Perpendicular to grain (flat grain)					
— High strength value		50	83	120	186
— Low strength value		47	73	103	151
Cleavage (lbs./sq. in. of width)					
Load to cause splitting					
— High strength value		56	61	70	87
— Low strength value		37	47	63	86
Coefficient of Linear Expansion					
Tangential		8.60 x 10^{-6}(0.00000860)			
Radial		6.92 x 10^{-6}(0.00000692)			
Longitudinal		1.99 x 10^{-6}(0.00000199)			
(inch per inch per °F)					

(Provided by Baltek Corp., Northvale, NJ)

CHAPTER 4

CONCEPTUAL DESIGN STUDIES

4.1 ARCH

An intensive design review was made of the present corrugated steel plate oval arch and concrete slab magazine configuration shown in Figure 1.1. Retention of the concrete floor slab and arch foundations was considered to be most cost effective with corrosion protection provided by presently specified drains and barriers.

An FRP semi-circular arch configuration was selected to replace the present magazine multi-radius, steel oval-arch section. This configuration was selected because of its high efficiency in resisting the external pressure applied by the earth embankment which is placed over the magazine for blast protection.

The semi-circular arch section is formed by two equal arc length FRP panels extending from the footings to the top center of the arch. This arrangement provides the following considered advantages:

a. All panels are identical and can be manufactured from one basic mold.
b. Field assembly labor is minimized because only one circumferential panel joint is employed per panel.
c. Individual panel size and configuration permit ready shipment by truck, rail, air or water.

An arch radius of 15 feet was established because it provides a magazine internal volume approximately equal to that of the present design. A magazine internal volume comparison is shown in Figure 4.1.

Because the modulus of elasticity of FRP is generally lower than that of steel, various FRP panel cross sections with increased moments of inertia were investigated to insure stability of the 30 foot span arch. Several of the semi-circular arch panel cross section conceptual designs developed for subsequent cost evaluation are shown in Figure 4.2.

4.2 END WALLS

The present steel arch magazine employs reinforced concrete end

walls at the entrance and rear. As shown in Figure 4.3, the concrete
rear wall is earth-covered and its top edge is formed to match the radii
of the steel oval arch. As shown in Figure 4.4, the entrance end wall
extends above the steel oval arch and retains the end of the earth embank-
ment over the arch. The entrance wall also includes wing walls for the
sloped embankment portions at both sides of the steel oval arch.

Several end wall conceptual designs employing FRP panels were
developed for subsequent evaluation. These design concepts are shown in
Figure 4.5.

Two conceptual designs (flexible and rigid) were developed for
the connection between the FRP end walls and adjacent arch panel edges
as shown in Figures 4.6 and 4.7. The flexible connection design emp-
loyed a standard roof expansion joint (recommended by Johns Manville
Corp.) and an FRP protective cover as shown in Figure 4.6. The flexible
sealing strip and installation clearance dimensions shown permit relative
motion between the arch panels and end walls during and after placement
of the earth embankment over the magazine. The edge sealing strip would
be adhesive bonded to the magazine end walls and arch panels. Tape would
be used to hold the edge sealing strip in place during curing of the ad-
hesive.

The rigid connection design consists basically of an adhesive
filled socket as shown in Figure 4.7.

15'R. FRP SEMI-CIRCULAR ARCH

PRESENT STEEL OVAL ARCH

(+)

(+)

(-)

(±)

(-)

(+)
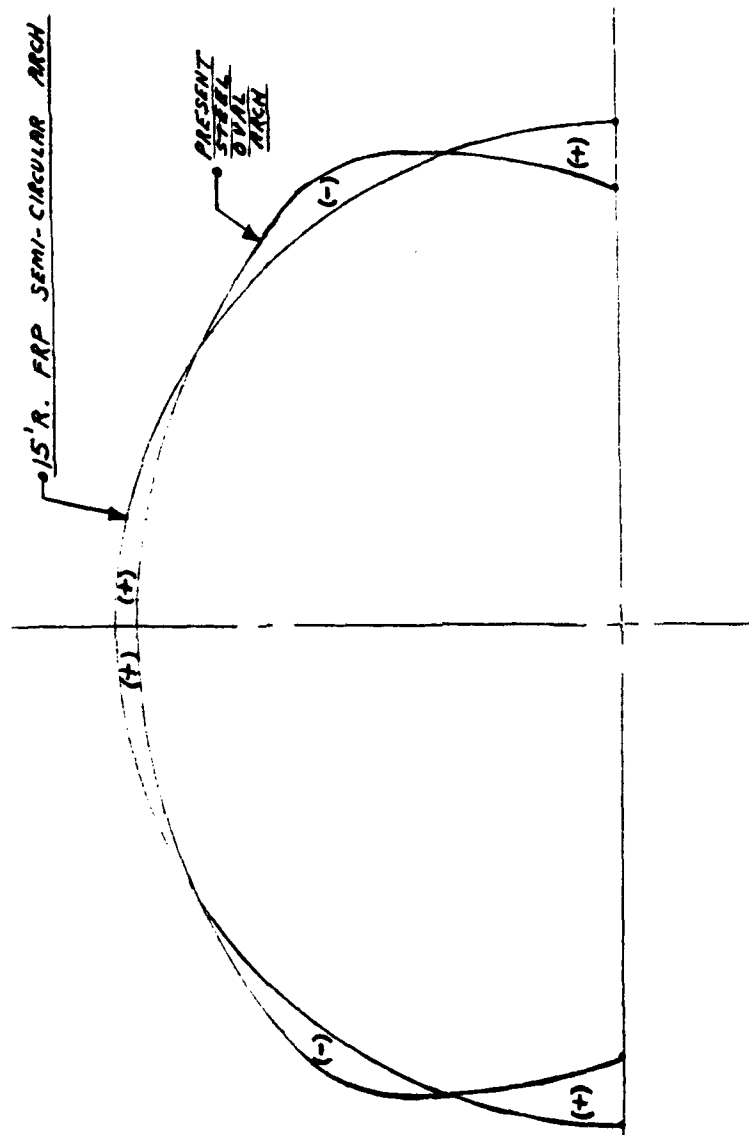
FIGURE 4.1

MAGAZINE INTERNAL VOLUME COMPARISON

EARTH EMBANKMENT

FRP ARCH PANEL

2 : 1

A

A

15 FT. R.

2'

GROUT

FOOTING

SLAB

END VIEW
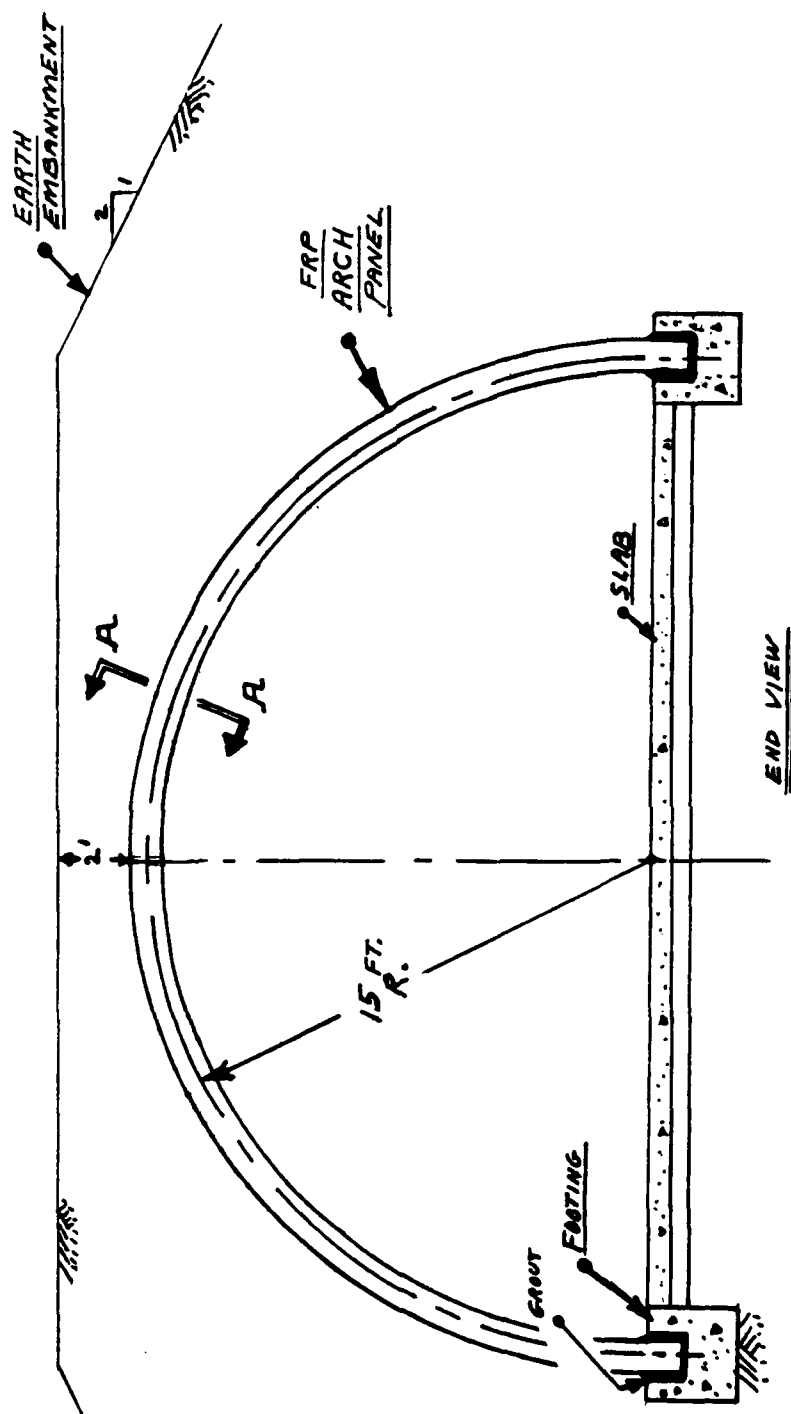
FIGURE 4.2 SH. 1 OF 4

ARCH PANEL CROSS SECTION CONCEPTS
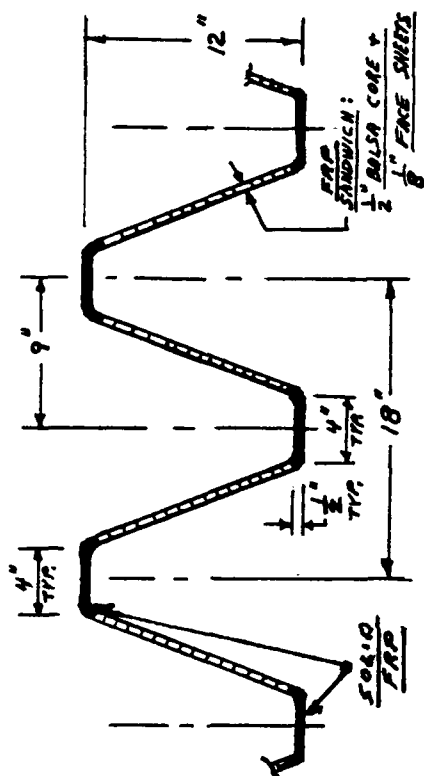
SECTION A-A

(FROM SH. 1)
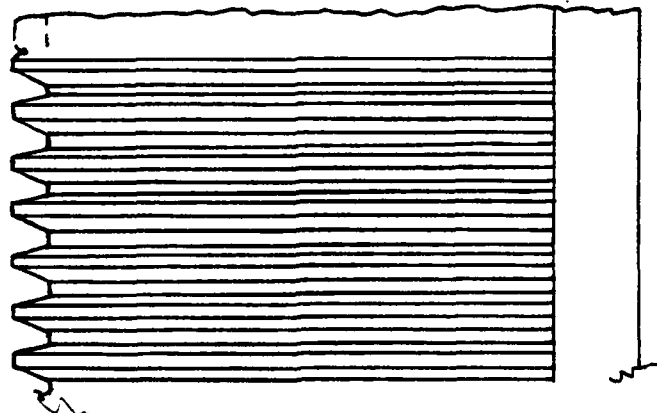
SIDE VIEW

FIGURE 4.2   SH 2 OF 4

SANDWICH:
$\frac{1}{2}"$ BALSA CORE +
$\frac{1}{8}"$ FACE SHEETS

18" PNL. WIDTH

9"

4" TYP.

FRP BOLT, NUT + GROMMETS
STRUCTURAL ADHESIVE + SEALANT

12"

4" TYP.

$\frac{1}{2}"$ TYP.

$\frac{1}{8}"$ THK. SHEET CORRUGATED

INTERIOR OF MAGAZINE

7' PNL. WIDTH

$\frac{3}{8}"$

METAL SPRING CLIP
STRUCTURAL ADN. + SEALT.

$\frac{1}{8}"$ THK. SH. CORRUGATED

12"

$\frac{3}{8}"$

INTERIOR JT. PNL. WITH SELF-TAPPING SCREWS

18"

METAL SPRING CLIP;
STR. ADN. + SEALT.

12"

7' PNL. WIDTH

INT. JT. PNL. WITH SELF-TAP SCREWS

FIGURE 4.2   SH 3 OF 4

ALTERNATES TO SECTION A-A ON SH. 2

Top section:

24" PNL. WIDTH

FRP BOLT, NUT, GROMMETS

STRUCTURAL ADH. + SEAL'T.

4"R.

6"R.

15"

SANDWICH:
½" BALSA CORE
⅛" FACE SH.

INTERIOR
OF
MAGAZINE

Middle section:

72" PNL. WIDTH

36"

2.5"

SANDWICH:
1½" CORE
3/16" FACE SH.

METAL SPRING CLIP
STR. ADH. + SEAL'T.

Bottom section:

9"

6"

SANDWICH:
5/8" CORE
⅛" FACE SH.

BOLT, NUT
STR. ADH. + SEAL'T.

18"

36" PNL. WIDTH

FIGURE 4.2   SH. 4 OF 4

ALTERNATES TO SECTION A-A ON SH. 2

STEEL ARCH

#8 @ 12" VERTICAL

#4 @ 12" EACH FACE HORIZONTAL

30# ASPHALT IMPREGNATED FELT

#3 @ 12" VERTICAL

DAMPPROOF EXTERIOR SURFACE OF REAR WALL

DOWELS TO MATCH VERT REINFORCING

12"

2'-0"

3-#4

SECTION G

24'-10"

1'-3"

#8 @ 12" VERTICAL

#4 @ 12" EACH FACE HORIZONTAL

#3 @ 12" VERTICAL

PLAN-REAR WALL

DAMPPROOF ENTIRE EXTERIOR CURB WALL SURFACE

€ ARCH

CONSTRUCTION JOINT

ELEVATION REAR WALL

FIGURE 4.3

PRESENT MAGAZINE REAR WALL

(OCE DWG. NO. 33-15-73)

PARTIAL ELEVATION PORTAL WALL

FIGURE 4.4 PRESENT MAGAZINE ENTRANCE WALL (OCE DWG. NO. 33-15-73)
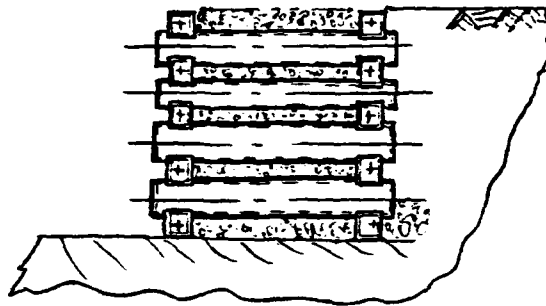
M — 1 —
FRP BOX SECTIONS USED AS CONVENTIONAL FILLED CRIB WALL
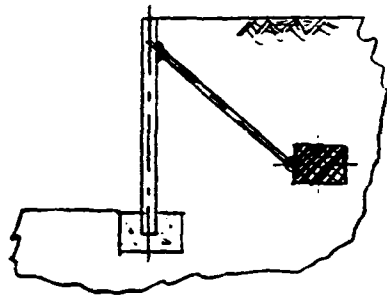
M — 2 —
GUY - ANCHOR SUPPORTED FRP WALL
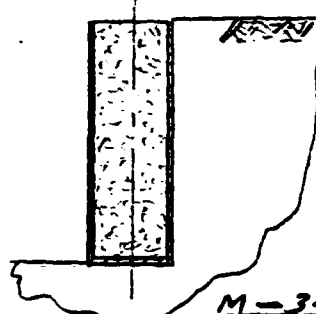
M — 3 —
EARTH-FILLED FRP - PIPE OR RECT. BOX WALL
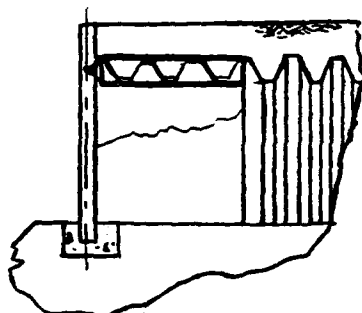
M — 4 —
SEMI-CIRC. ARCH END PANEL WITH FRP SHEETS ADDED TO FORM BOX CURVED BM. FOR WALL SUPPORT

M — 5 —
CANTILEVERED FRP U-PANEL WALL

FIGURE 4.5 FRP END WALL DESIGN CONCEPTS (SH. 1 OF 2)
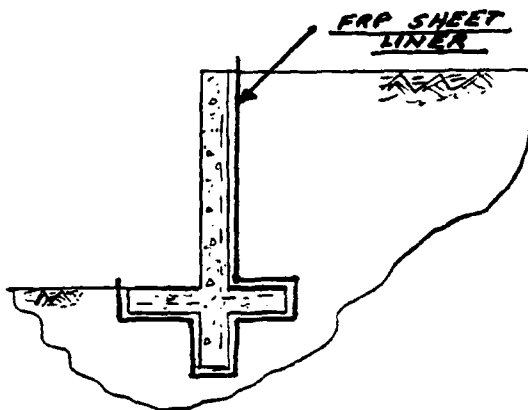
N-6-
FRP SHEET
LINER ON
REINF. CONC.
WALL
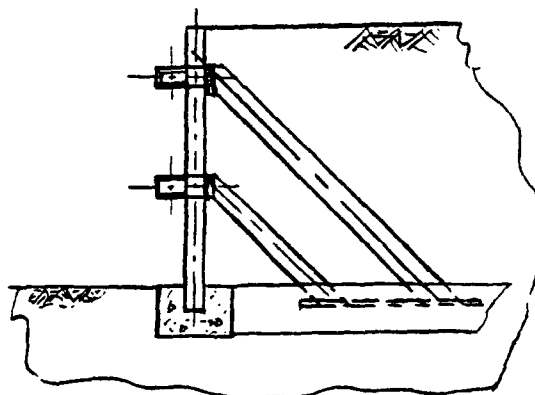
N-7-
END WALL
LATERALLY
SUPPORTED
BY HORIZ.
BEAMS +
END DIAGONAL
BRACES
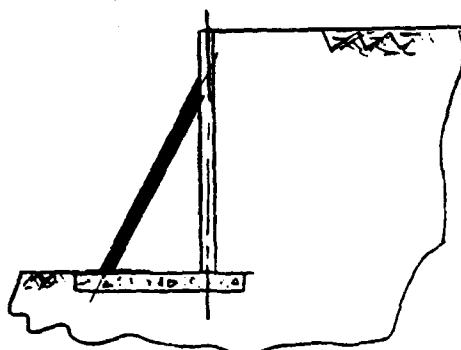
N-8-
END WALL
STRUT
SUPPORTED

FIGURE 4.5 (SH. 2 OF 2)

VERTICAL END WALL

ADH.

FRP EDGE COVER PANEL

ROOF EDGE SEALING STRIP

FRP ROOFING TAPE

$2"\frac{1}{2}$

$\frac{1}{8}"$

SEMI-CIRC ARCH ROOF VEE PANEL

$15\frac{1}{2}'R.$
(REF.)
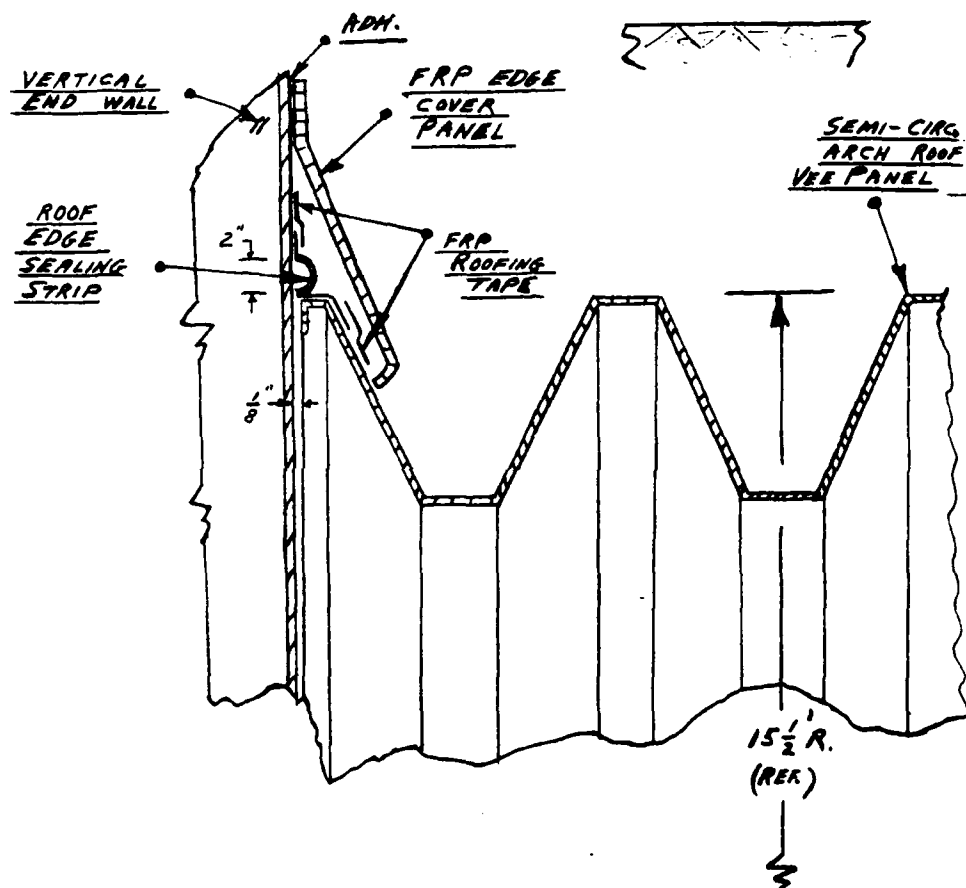
FIGURE 4.6 FLEXIBLE END WALL/ARCH EDGE JOINT CONCEPT

FRONT
FRP
CRIB
WALL
U-PANEL
FLANGE

FLGD.
PANEL

SEALANT/
ADHESIVE

SEMI-
CIRCULAR
ARCH
PANEL

ENTRANCE
WALL

U-PANEL
SEMI-
CIRCULAR
MOLDED
FLANGE

SECTIONAL
ELEVATION
VIEW
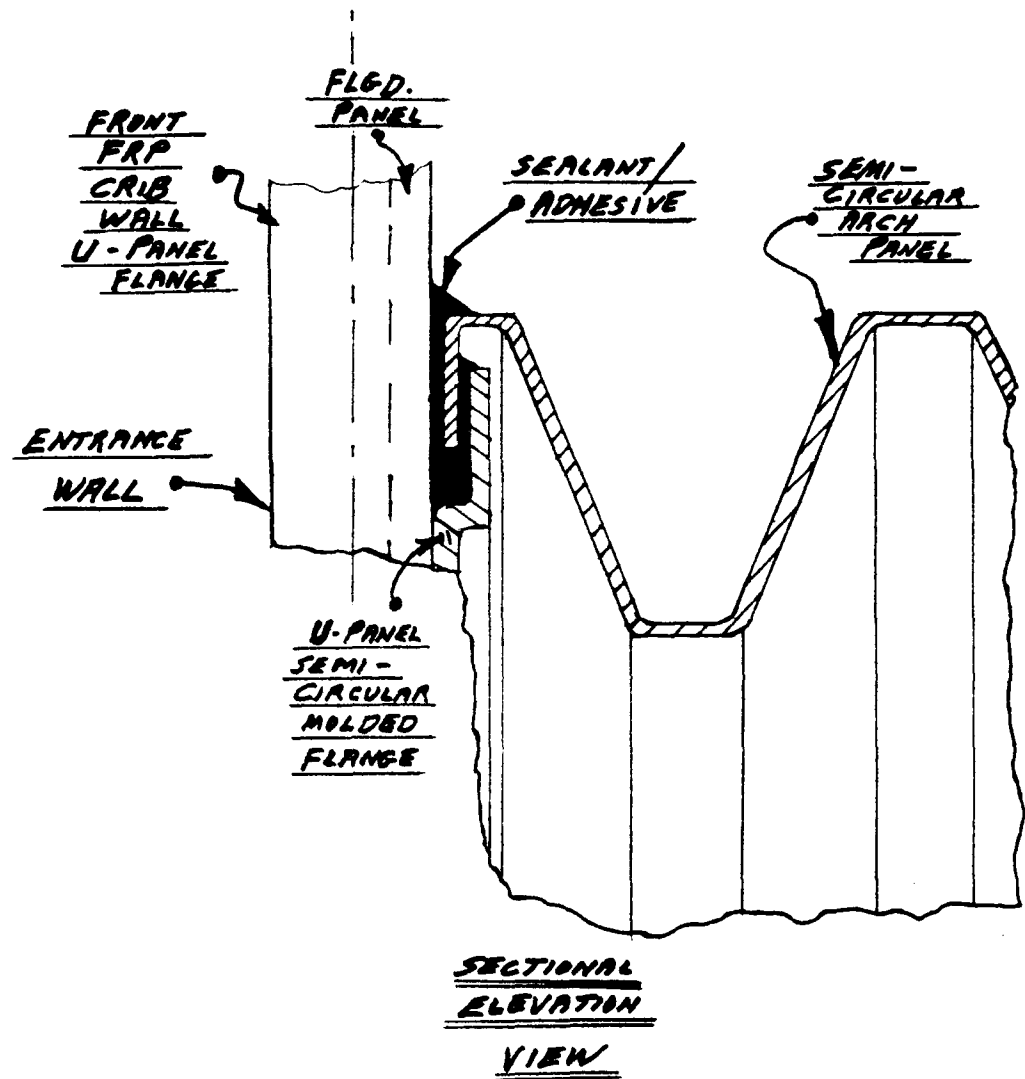
FIGURE 4.7 RIGID END WALL/ARCH PANEL EDGE JOINT CONCEPT (SH. 1 OF 2)

SEMI-CIRCULAR ARCH
JOINT DETAIL
AT ENTRANCE WALL

FRP
REAR
VEE PANEL
END WALL

FRP
SEMI-CIRCULAR
MOLDED FACE/FLG.

SEALANT/
ADHESIVE

FRP
SEMI-
CIRCULAR
ARCH
PANEL

℄
WALL

SECTIONAL
ELEVATION
VIEW
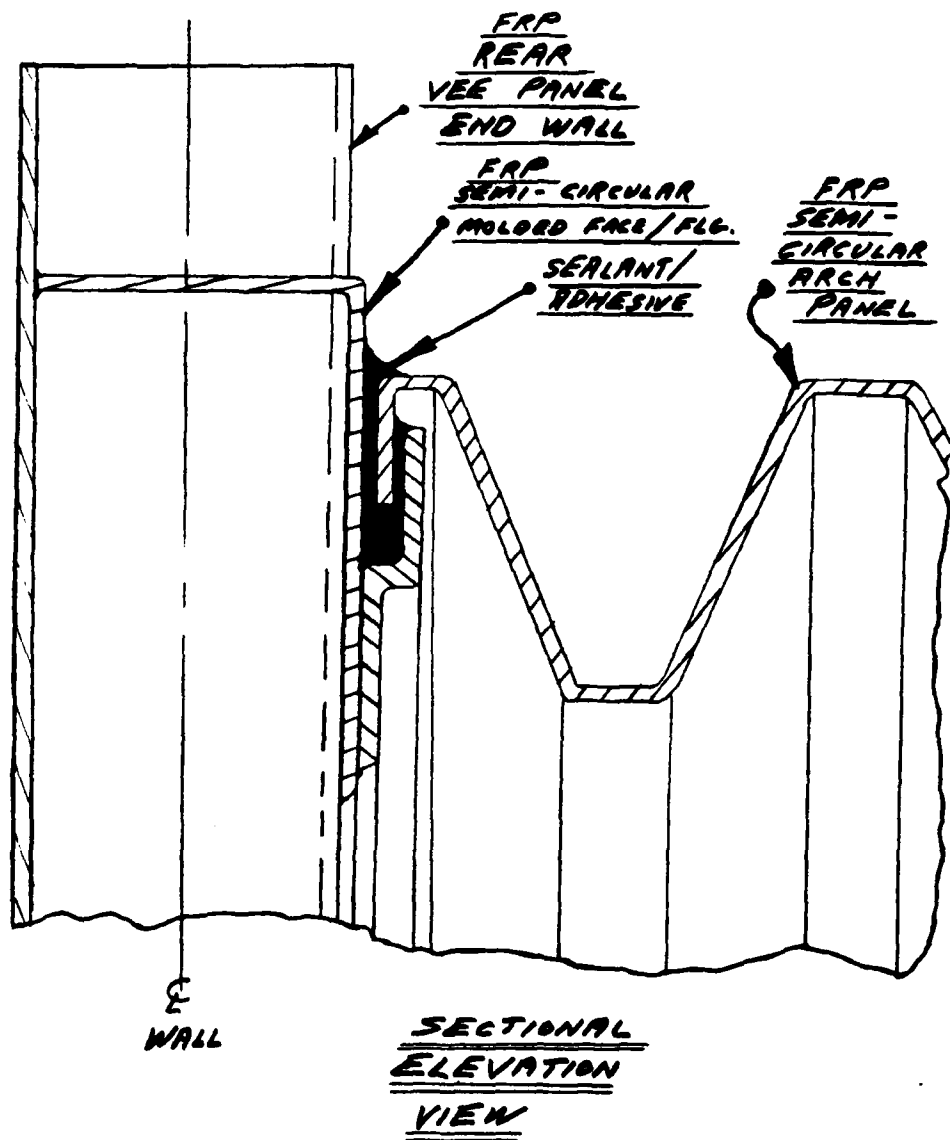
SEMI-CIRCULAR ARCH
JOINT DETAIL
AT REAR WALL

FIGURE 4.7 (SH. 2 OF 2)

CHAPTER 5

FRP MAGAZINE DESIGN

5.1 CONFIGURATION

The FRP magazine configuration developed as an alternative to the specified present steel oval arch structure is shown in Figure 5.1. The magazine is constructed completely of FRP panels except for the internal concrete floor slab and arch foundations.

Site preparation, concrete floor slab, arch foundations, drains, capillary water barrier, subgrade and vapor barrier requirements would be similar to those presently specified on OCE drawing no. 33-15-73.

5.2 ARCH

The selected FRP semi-circular arch panel design has the squared-vee cross-section as shown in Figure 4.2, sheet 2. The panel consists of solid FRP at the top and bottom horizontal portions of the vee, and balsa core FRP sandwich construction on the inclined portions.

The panel vee cross section was selected over the other concepts developed because it was considered to offer the following advantages:

a. Efficient use of material.
b. Minimal required manufacturing labor and forms.
c. High nestability for reduced shipping colume.
d. Symmetrical cross section efficient in bending.
e. Minimal reduction of magazine useful internal volume.

These 90 degree arc length by $7\frac{1}{2}$ feet wide panels permit magazine construction to required lengths by continued placement and attachment of adjacent panels. Details of these panels are shown in Figure 5.2.

To achieve increased inherent stability of the arch, the lower ends of the panels are grouted at the foundations.

The connection between adjacent circumferential edges of the FRP magazine semi-circular arch panels is shown in Figure 5.3. During field erection, structural adhesive/sealant would be applied to panel edges

31

and then FRP wedge blocks would be driven over the edges as shown (approx. 6" apart) to maintain panel alignment during curing of the adhesive/sealant. The wedge blocks and adhesive/sealant would be applied by workers standing on portable staging located on the magazine floor slab.

The top connection between adjacent pairs of semi-circular arch panels is shown in Figure 5.4. This panel end joint design employs a socket molded into one end of the panel as shown in Figure 5.5. During field erection, the straight panel ends would simply be inserted and adhesive bonded within the opposite panel socket ends. Major features of this connection are: its effective utilization of adhesive lap shear strength; direct load paths and minimal required field assembly labor. Similar adhesive bonded socket joints are successfully employed on standard FRP underground units such as piping and prefabricated manhole panels.

The rigid connection between the FRP end walls and adjacent arch panel edges as shown in Figure 4.7 was selected over the alternate flexible design concept, after subsequent detailed analysis, because of its considered superior reliability.

5.3 REAR WALL

The design of the FRP magazine rear wall is shown in Figure 5.6. This wall consists of vertical vee panels similar in cross section to the semi-circular arch panels. The top ends of these vertical panels extend approximately 12" above the semi-circular arch panels. The vertical panels are designed for the lateral soil pressure exerted by the embankment. They are supported horizontally by the edge of the floor slab and by the earth embankment annulus beyond the outer edge of the arch panels. Manually tamped cohesionless back fill would be located at the outer edge of the panels as shown. The complete wall would be formed by placement of adjacent vertical panel sections. Edges of adjacent panels would be adhesive-bonded as the arch panels. The bottom of the wall would

be grouted into the floor slab.

5.4 ENTRANCE AND WING WALLS

The design of the FRP magazine entrance end wall and wing walls
is shown in Figure 5.7. They are designed as solid face crib walls and
are formed by FRP panels. The front and rear header wall panels are
designed to resist lateral pressures developed in the crib when filled
with soil prior to construction of the magazine embankment. The FRP
front-to-back tie plates (stretcher panels) are designed for the tensile
loading produced by lateral earth pressure acting on opposite header
panels. A factor of safety of 1.5 on the stability of this gravity
type retaining wall is obtained by spacing the front and rear header
panels at a minimum horizontal distance equal to one half the height of
the retained soil. The front and rear header panels are of FRP sand-
wich construction with a 30" span between flange stiffeners as shown in
Fig. 5.7, sheet 3. The tie plates would be installed and adhesive
bonded between adjacent header panel flanges. Bolts would be installed
through the tie plate ends and header panel flanges to permit ready
field erection and to maintain panel alignment during curing of the struc-
tural adhesive. Subsequent corrosion and loss of the steel bolts would be
unimportant because, the structural adhesive would provide necessary
strength. Cohesionless fill would be placed within the crib to permit
drainage and to provide desired high friction and shear strength. The
fill placed within the crib would also form a portion of the required
magazine earth embankment. Considered advantages of this design may be
listed:

- Effective utilization of materials.
- Present wing wall reinforced concrete footings are not req'd.
- Minimal required shipping volume.

Additional security protection can be easily provided in the FRP
magazine entrance end wall, when necessary, by placement of expanded
metal grating within the panel during molding.

Relative disadvantages of the alternative FRP end wall design

33

concepts shown in Figure 4.5 were determined to be as follows:

Fig. No. 4.5	Major Relative Disadvantage
M -1-	Requires larger quantity of material.
M -2-	Anchorage reliability is highly dependent on competent compaction of backfill.
M -3-	Requires larger quantity of material.
M -4-	Arch ring beam only provides support for a portion of the end wall.
M -5-	Requires larger quantity of material.
N -6-	Puncture of the FRP protective liner during improper backfilling would not be detected.
N -7,-8-	Inclined members could be damaged by construction equipment.

The FRP magazine entrance door, with a required minimum clear opening of 8' X 9'-6" high is considered to be a commercially available, fiberglass, sectional, vertically opening door assembly as illustrated by Figure 5.8.

When required, the present magazine design steel door and reinforced concrete framing can be easily incorporated in the FRP magazine entrance end wall. In the event that the present reinforced concrete end walls are required at certain magazine locations, FRP arch panel edge connections can be made as shown in Figure 5.9. These connection details are similar to those indicated on Sheet 4 of Dept. of the Army drawing 33-15-73.

5.5 PANEL JOINT ADHESIVES AND SEALANTS

FRP panel joint structural adhesives and sealants selected are considered to be: cost effective, proven, and suitable for field usage on large FRP panels.

3M Co. number 5200 Scotch Seal marine bedding sealant has been selected for the arch panel/foundation joints; arch panel circumferential edge joints, and general usage. This one-part sealant forms a rubbery, extremely strong, waterproof seal. It is non-shrinking,

34

and is commonly used for the manufacture and maintenance of FRP boats.

H.B. Fuller Co. FRP reactive adhesive was selected for the higher stressed joints such as the arch panel edge/end wall connection, adjacent FRP panel joints in the end walls, and at the arch panel top end flanged socket joints. Major advantages of this two part product are that it is among the toughest structural adhesives and it requires no mixing in the field, because the activator is applied to one mating part and the base adhesive is applied to the opposite mating part.

5.6 MANUFACTURING METHODS

Considering low to medium volume production rates (less than 25, sixty feet long magazines per year), hand lay-up and spray-up FRP manufacturing methods would be most applicable. These methods (described in Ref. 4) are commonly used for production of large, high strength parts. Associated tooling costs are relatively low and these contact molding methods are widely used and proven.

Panels produced by more automated methods such as compression molding with steel dies would not be economically feasible until panel production quantities of approximately 500, sixty feet long magazines per year are required.

5.7 PACKING AND SHIPPING

Maximum FRP panel sizes were established to minimize panel joints and also to permit ready shipment from the manufacturer to world wide installations by truck, rail, ship or air. Minimal packing material, e.g., spacer blocks and strapping, would be required for these rugged FRP panels. Integral lifting attachments would be incorporated in each FRP panel to facilitate handling and field erection. Calculated maximum single FRP panel weight is approximately 1500 pounds.

Arch and end wall panels are of vee and U cross-sections and therefore can be nested compactly for minimum shipping volumes.

The shipping weight of arch panels for a 60 feet long magazine was estimated to be 24,000 pounds for FRP as compared to 41,000 pounds for the present steel plate.

5.8 FIELD ERECTION PROCEDURE

Another major advantage of the developed FRP magazine design is that it employs large shop-fabricated panel sections suitable for rapid field erection. Erection of the FRP semi-circular arch panels would commence after placement and set up of the magazine concrete floor slab and arch foundations.

A portable staging would be located on the floor slab to provide convenient worker access during panel alignment and the installation of panel joint wedge blocks. Application of structural adhesives to all FRP panels edges would be readily performed at ground level prior to erection; allowing approximately 30 minute adhesive set-up time. Temporary wooden shims would be used at the base of the arch panels to facilitate panel edge alignment and to correct for any concrete footing irregularities.

Upon completion of erection of the arch panels to the edges of the end wall foundations, grouting of arch panels and footings would commence.

The vertical end wall panels would then be placed into their footings and positioned so their semi-circular molded flanges engage the end arch panel circumferential edges (see Fig. 4.7). Adjacent vertical edges of the end wall panels would then be joined and the end walls and footings would be grouted. At this time additional sealant/adhesive would be applied externally at the arch panel and end wall joints.

Installation of the remaining FRP panels of the crib type entrance wall and wing walls would also proceed.

Next, granular fill would be placed within the entrance and wing crib and on the arch panel adjacent to the top edge of the rear wall.

Placement of the earth embankment over the magazine would then continue until completion. Backfilling would be performed per present steel arch magazine requirements repeated below (Reference 5). Fill would be placed on each side of the arch and over the arch in a manner to obtain uniform loading on the sides and top of the arch. Fill would be placed in successive horizontal layers of 8 to 12 inches in loose depth.

Filling operation would commence at both magazine ends and continue uniformly towards the center.

Compaction would be accomplished by sheep-foot rollers, pneumatic-tired rollers, steel-wheeled rollers or other equipment suitable for the soil being compacted. Heavy equipment should not be run over or used for compaction of the fill directly above or closer than 6 feet to the sides of the arch, nor should heavy equipment be operated closer than 6 feet to the magazine rear wall or to the rear face of the magazine front wall. Heavy equipment for spreading and compacting backfill should not be operated closer to foundation or retaining walls than a distance equal to the height of backfill above the top of footing; the area remaining should be compacted by power driven hand tampers suitable for the material being compacted. Backfill should not be placed in wet or frozen areas and it should be free of debris, roots, frozen matter, fat clay (CH), and stones with any dimension greater than 2 inches.

5.9 MAINTENANCE

No required maintenance is anticipated for the developed FRP magazine design over its required service life of 20 years.

REAR WALL

BACKFILL

ARCH PANELS

ENTRANCE &
WING
SIDE WALLS
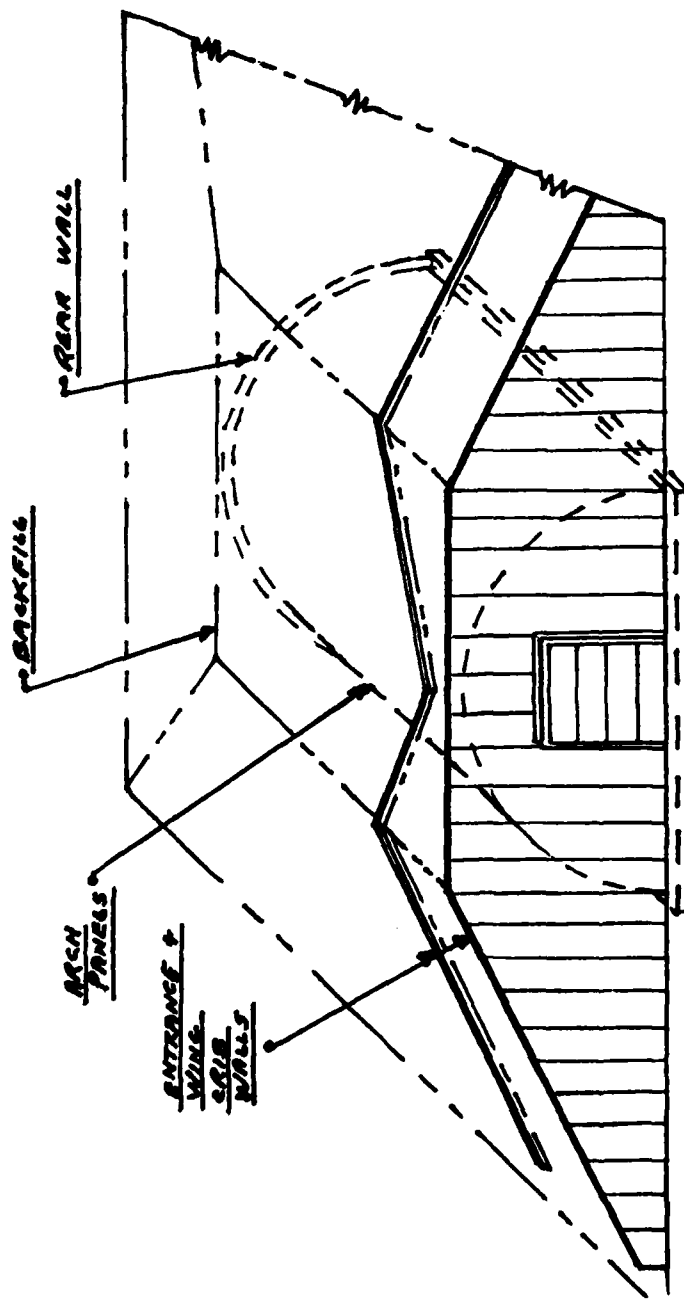
FIGURE 5.1 GENERAL CONFIGURATION — FRP MAGAZINE

180" R.

6"

12"

90°

(FRP
LEFT HAND
SEMI - CIRCULAR
ARCH PANEL
END VIEW)

PANEL
CONST.
ALL 3/8 -
THK. SOLID
SHEET

PANEL
CONST.
PER
FIG. 4.8

PANEL
CONST.
PER FIG.
4.1.3

25"

1/2"

9"
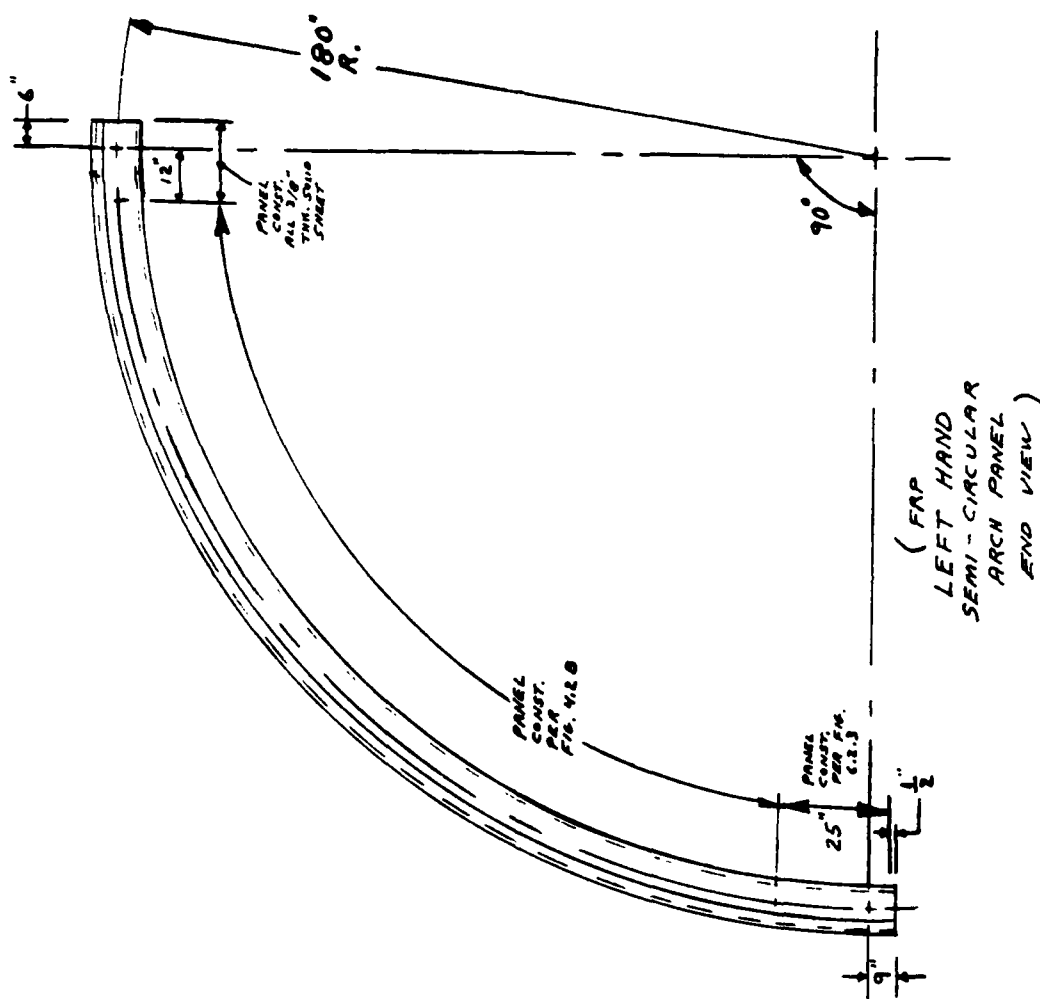
FIGURE 5.2 FRP SEMI-CIRCULAR ARCH PANEL (SH. 1 OF 3)

FIGURE 5.2 (SH. 2 OF 3)

(FRP RIGHT HAND SEMI-CIRCULAR ARCH PANEL END VIEW)

90"
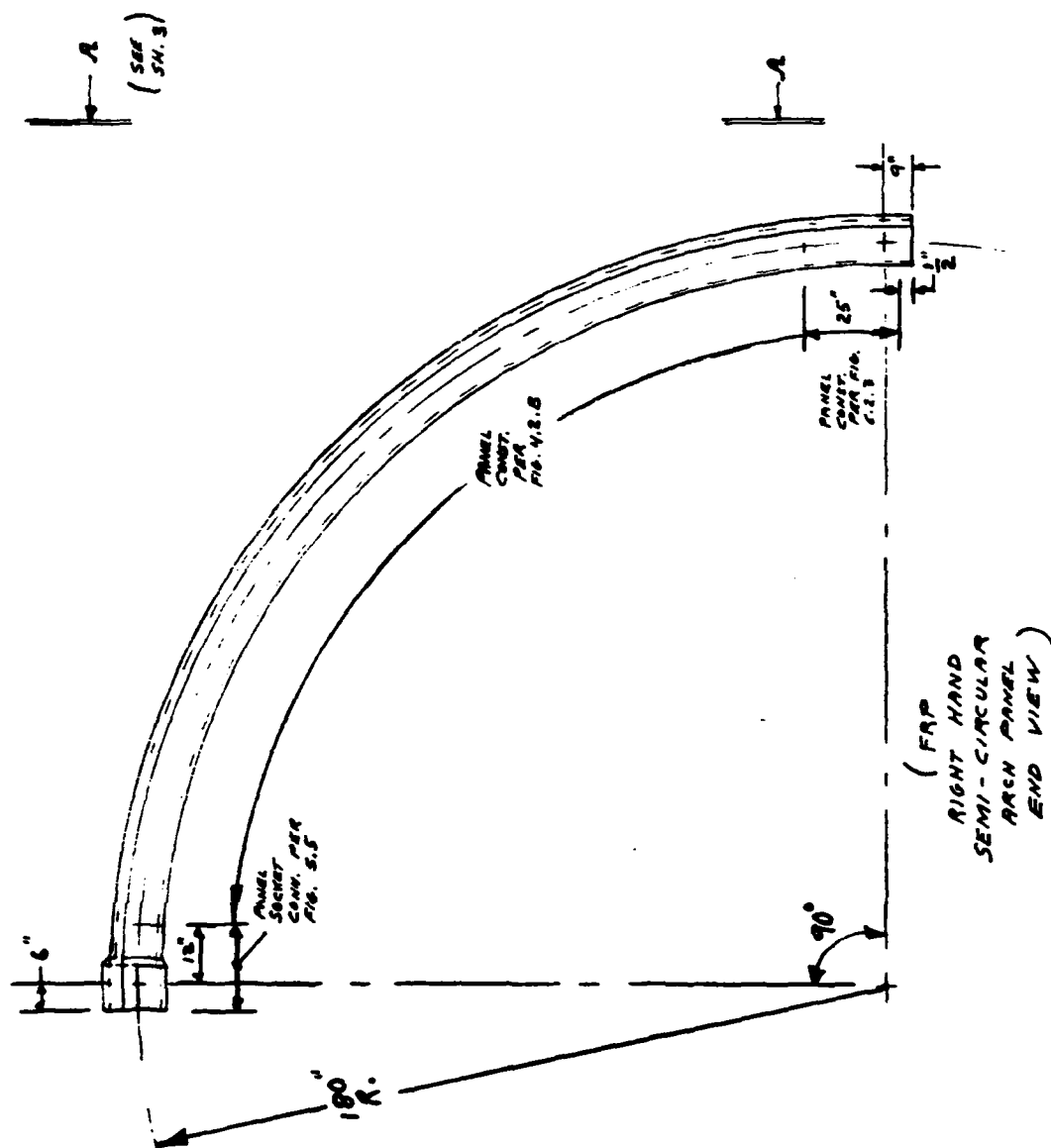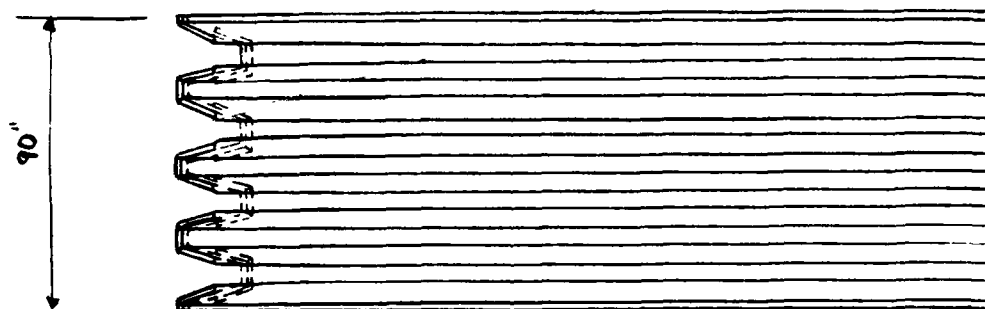
SIDE VIEW A-A

FIGURE 5.2 (SH. 3 OF 3)

[EARTH EMBANKMENT]

STRUCTURAL
ADHESIVE/
SEALANT

SEMI-CIRCULAR
ARCH PANEL
CIRCUMFERENTIAL
EDGE

SEMI-CIRCULAR
ARCH PANEL
CIRCUMFERENTIAL
EDGE

CORRUGATED
FRP
VEE
PANEL
(TYP.)

15'-6"
R.
(REF.)

FRP WEDGE BLOCK
(1" THK.)
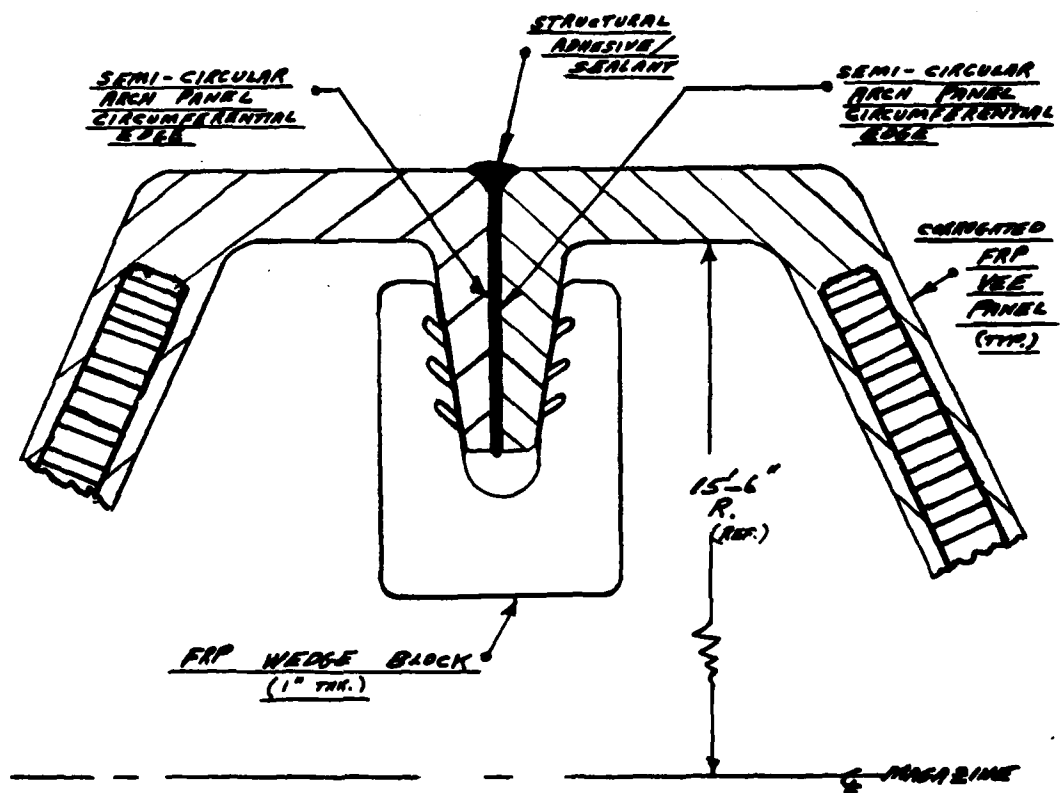
℄ MAGAZINE

[MAGAZINE INTERIOR]

FIGURE 5.3   CONNECTION BETWEEN ADJACENT ARCH PANEL EDGES

ARCH
L.H. PANEL
(TYP.)

ARCH
R.H. PANEL
(TYP.)

15' R.

FLOOR
SLAB

FRP
MAGAZINE
SEMI - CIRCULAR
ARCH PANEL
ASSEMBLY

PANEL
WITH SOCKET
END

STRUCTURAL
ADHESIVE

PANEL
WITH
STRAIGHT
END

15'-0"
R.
(REF.)
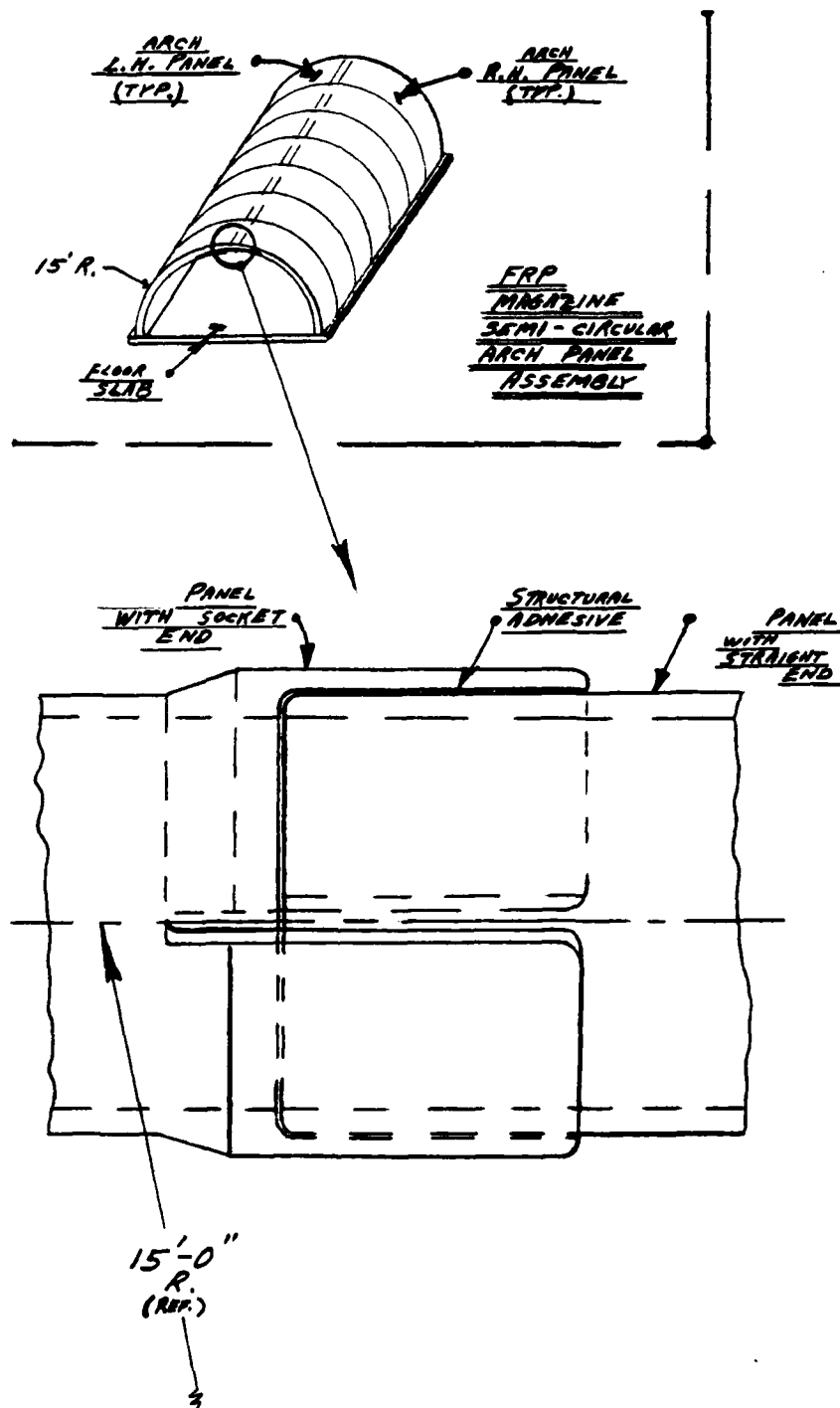
FIGURE 5.4   ARCH PANEL TOP END CONNECTION
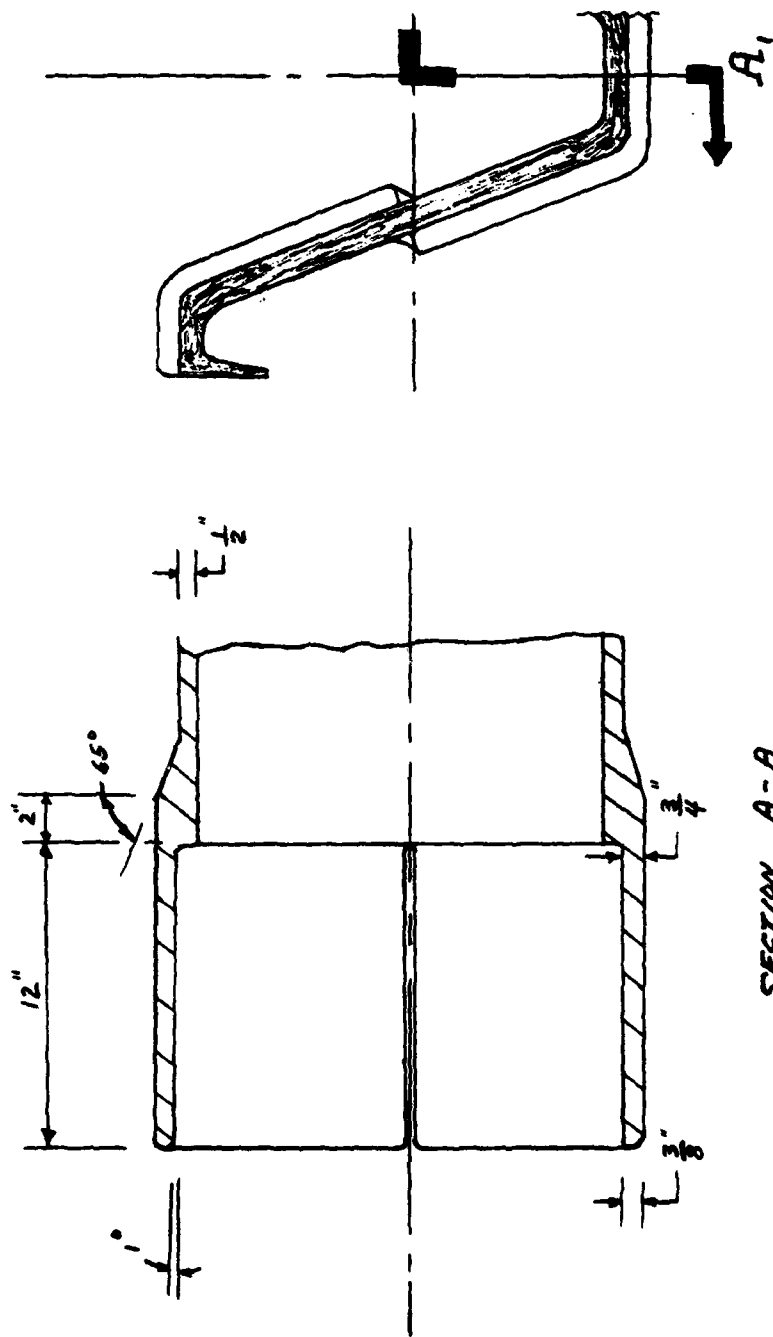
SECTION A-A,

FIGURE 5.5 ARCH PANEL END MOLDED SOCKET

VEE PANEL END WALL

CONTINUOUS FILL

EARTH EMBANKMENT

ARCH PANEL

SIDE VIEW

REAR END WALL

ELEVATION
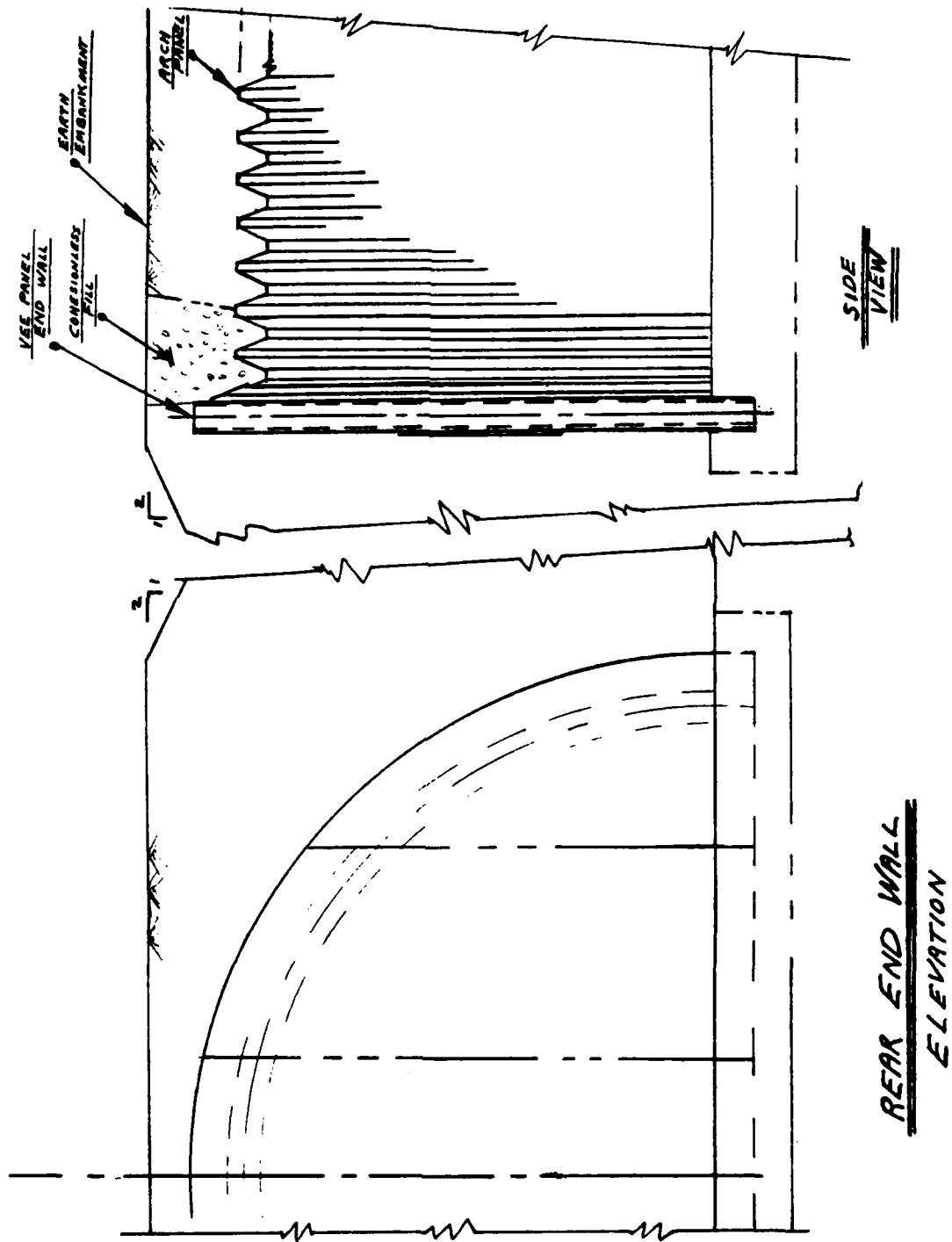
FIGURE 5.6   FRP MAGAZINE REAR WALL

PLAN VIEW

SYMMETRICAL
ABOUT CENTERLINE
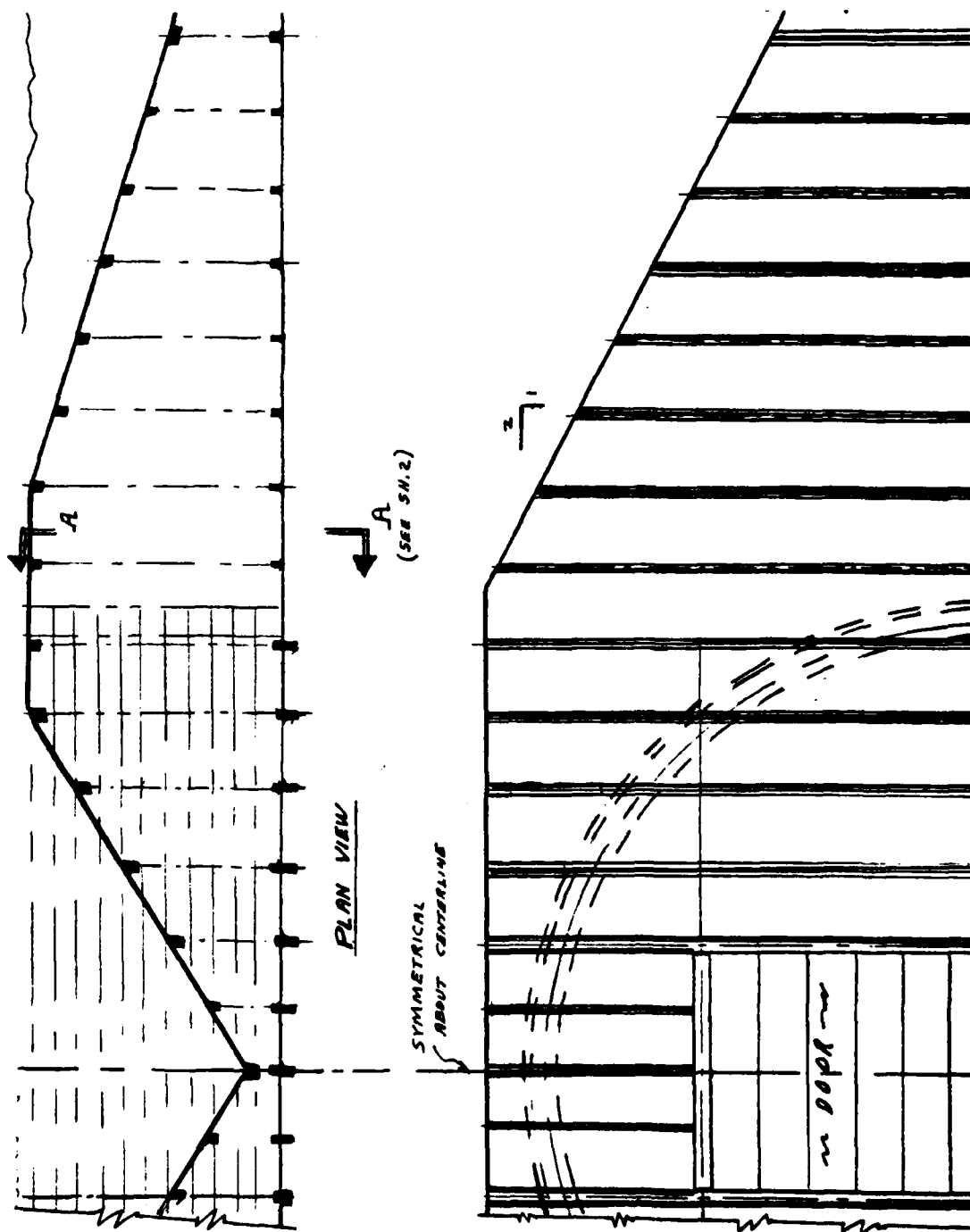
FIGURE 5.7 FRP MAGAZINE ENTRANCE AND WING WALLS (SH. 1 OF 3)

RETAINING
WALL
REAR
PANELS

COHESIONLESS
FILL

EARTH
EMBANKMENT

SEMI - CIRC.
ARCH PNLS.

TIE
PLATE
(TYP.)
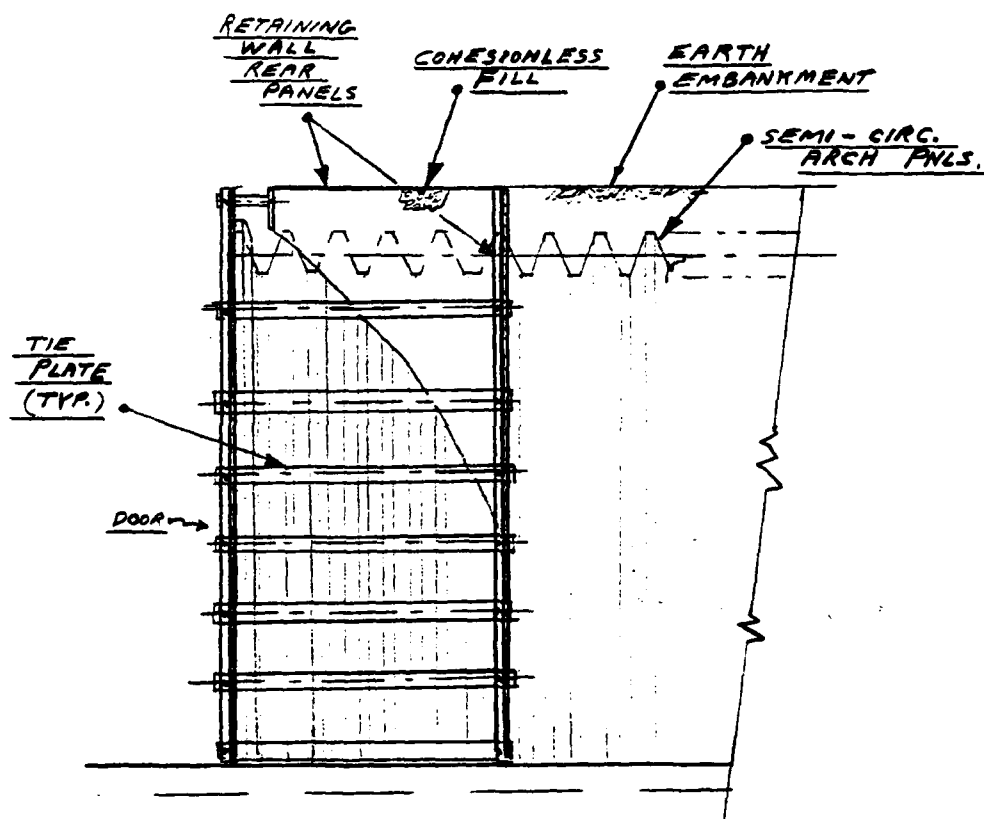
DOOR

(FROM SH.1)
SECTION A-A

FIGURE 5.7 (SH. 2 OF 3)

R. OPTIONAL

6" FLANGE

$\frac{3}{8}$"

$\frac{3}{8}$"

2'-6"

$\frac{7}{8}$" DIA. THRU 33 PLACES IN EACH FLANGE

2" TYP. BOTH SIDES

TOP

6" TYP. TOP + BASE

6" CTR. TO CTR. TYP.

17'-0"

SANDWICH: $1\frac{1}{4}$" CORE; $\frac{1}{8}$" FACE SHEETS

BASE

FIGURE 5.7 (SH. 3 OF 3) ENTRANCE END WALL PANEL— TYPICAL CONSTRUCTION

531 SERIES FIBERGLASS DOORS
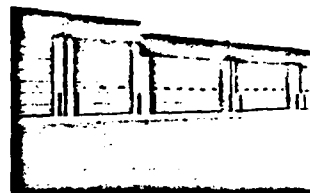
OP/CP DESCRIPTION

Here is a fiberglass, sectional, upward-acting door that offers you not only economy, but good looks. It is ideal where additional light is needed and rough treatment is not a problem.

A simple hosing down once in a while will keep it looking great for years. And you never have to worry about it splitting, cracking, curling or rotting.

TS/SPECIFICATIONS

The stiles and rails are extruded from 6063T6 aluminum alloy to produce a nominal wall thickness of 2". Center rails are designed with weather joint. Reinforcing fins on intermediate rails are standard on doors 10'3" and wider.

Deeply ribbed white, green or sand fiberglass panels extend the full width of each section. They are secured to both the end and center stiles and are sealed to the end stiles with polyurethane tape.

The color is impregnated into the fiberglass so it's permanent.

The hinges and fixtures are galvanized steel. The full floating ball bearing rollers are hardened steel.

The lock is a five-pin tumbler lock with a single unit lock mechanism.

All tracks are galvanized steel with Miracle Wedge weather closures. Depending upon the door size the tracks are 2" or 3". The verticals are bracket mounted for wood jambs or angle mounted for steel jambs.

Size Limitations

Track Size	Doors Not to Exceed		
	Wide	High	Sq.Ft.
2"	24'1"	16'1"	340
3"	26'2"	24'1"	600

Schedules — Panels

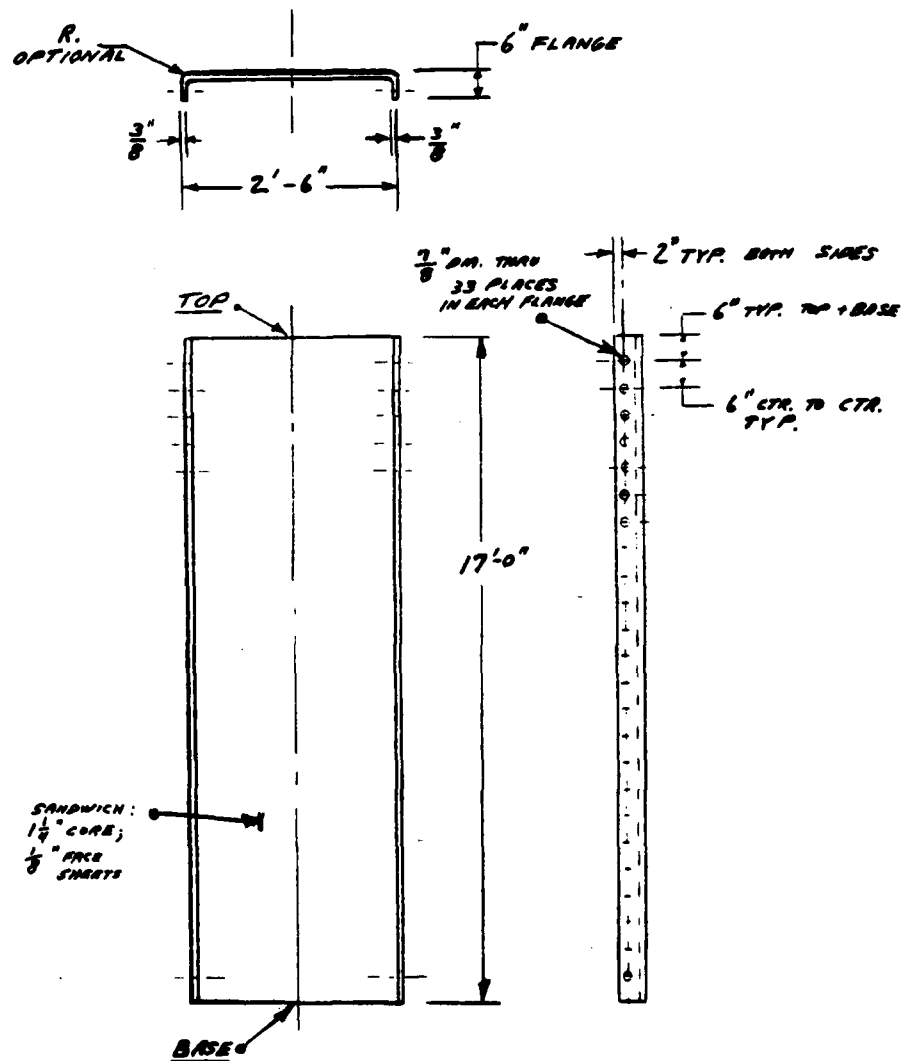| door width	number of panels
to 12'2"	3
12'3" to 16'2"	4
16'3" to 19'2"	5
19'3" to 22'2"	6
22'3" to 26'2"	8
26'3" to 33'2"	10

Sections

door height	number of sections
to 8'1"	4
8'2" to 10'1"	5
10'2" to 12'1"	6
12'2" to 14'1"	7
14'2" to 16'1"	8
16'2" to 18'1"	9
18'2" to 20'1"	10
20'2" to 22'1"	11
22'2" to 24'1"	12

OM/OPERATION, MAINTENANCE

A hand pull rope operates the door. All service and parts are available through your local Distributor of The "OVERHEAD DOOR."

OPTIONS

A chain hoist is recommended for doors over 13' high. Glazing, 17" x 4" with special glazing mould.
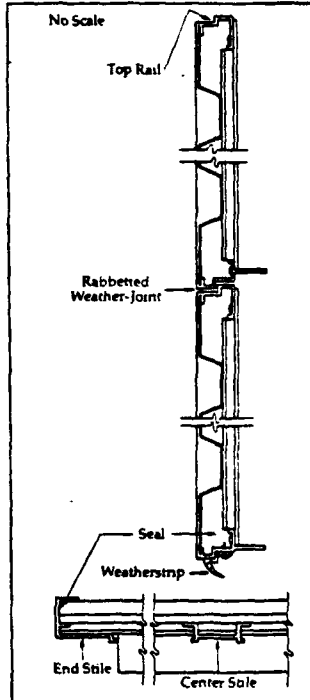
$U = 1.15°, R = .87°$

No Scale

Top Rail

Rabbetted Weather-Joint

Seal

Weatherstrip

End Stile

Center Stile

FIGURE 5.8   FRP ENTRANCE DOOR (SH. 1 OF 2)

JAMB, FRAMING AND COUNTERBALANCE PAD DETAIL
. . . required on all installations

The dimensions and locations of the framing and pads vary with the individual installation. Consult your "OVERHEAD DOOR" distributor for exact dimensions and details.

Opening Width

½ Opening Width   ½ Opening Width

8"   12"   12"   8"   4"

For Doors 18'3" And Over

For Doors 18'3" And Over

Headroom Varies

Headroom Varies

All Pads Flush With Jambs

All Jambs & Pads by Others

Opening Height

Opening

Opening Height

Wood Jamb

Steel Jamb

STANDARD 2" TRACK

This type track recommended for most installations of large or heavy doors; however, tracks should be designed to stay as near the wall and ceiling as possible. Posi-tension drums available on torsion spring equipped doors up to 18'1" high.

Opening Height Plus 1'6"

Headroom 16½"

See Type of Door For Size Limitations

Opening Height

No Scale

Steel Jamb   Opening Width   Wood Jamb

1"

2"

4½"   2" Track   3½"

HIGH LIFT TRACK

For situations requiring higher than normal clearance, specify The "OVERHEAD DOOR" with high lift track. It's counterbalanced with one or more torsion springs. Extension springs are not available with high lift tracks.

For size limitations on either the 2" or 3" track, see the type of door it is to be used with.

Overhead Door Corporation recommends the use of high lift track to locate the door as near the ceiling as possible.

Posi-tension drums are not available.

Varies

Varies

Headroom — Maximum 11'6"

2" or 3" Lift Clearance Track

Roof Line Track

53

Opening Height

No Scale

FIGURE 5.8 (SH. 2 OF 2)

12"
REF.

REF.
℞ 3/8" × 4" × 4"
TYP. 3 PLACES

STEEL
3/4" ⌀ BOLT
AT 9" CTRS.
REF.

#3
SPACER
BAR
REF.

REINF.
CONC.
ENTRANCE
WALL

6" MIN. BOTH SIDES

SEALANT +
FLASHING

FRP
SEMI-
CIRC.
ARCH
PANEL

℄
WALL

REF. DEPT. OF THE ARMY
DRAWING NO.
33-15-73, SHEET 4 OF 9
DETAIL 2

SECTIONAL
ELEVATION VIEW
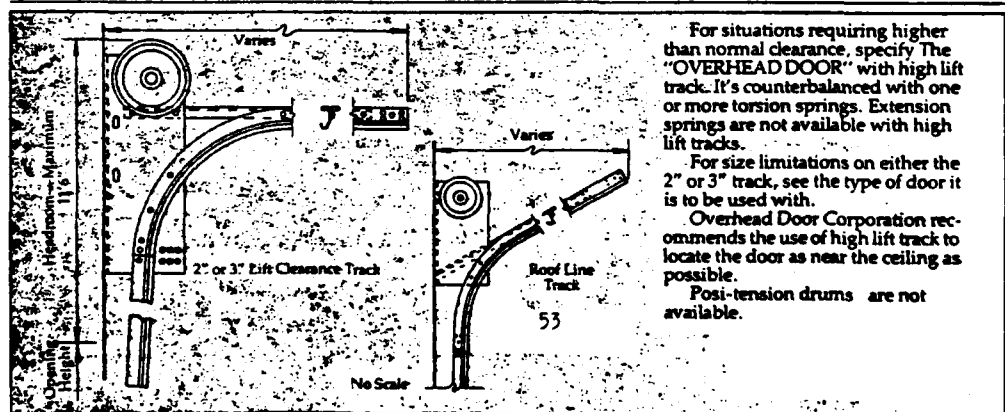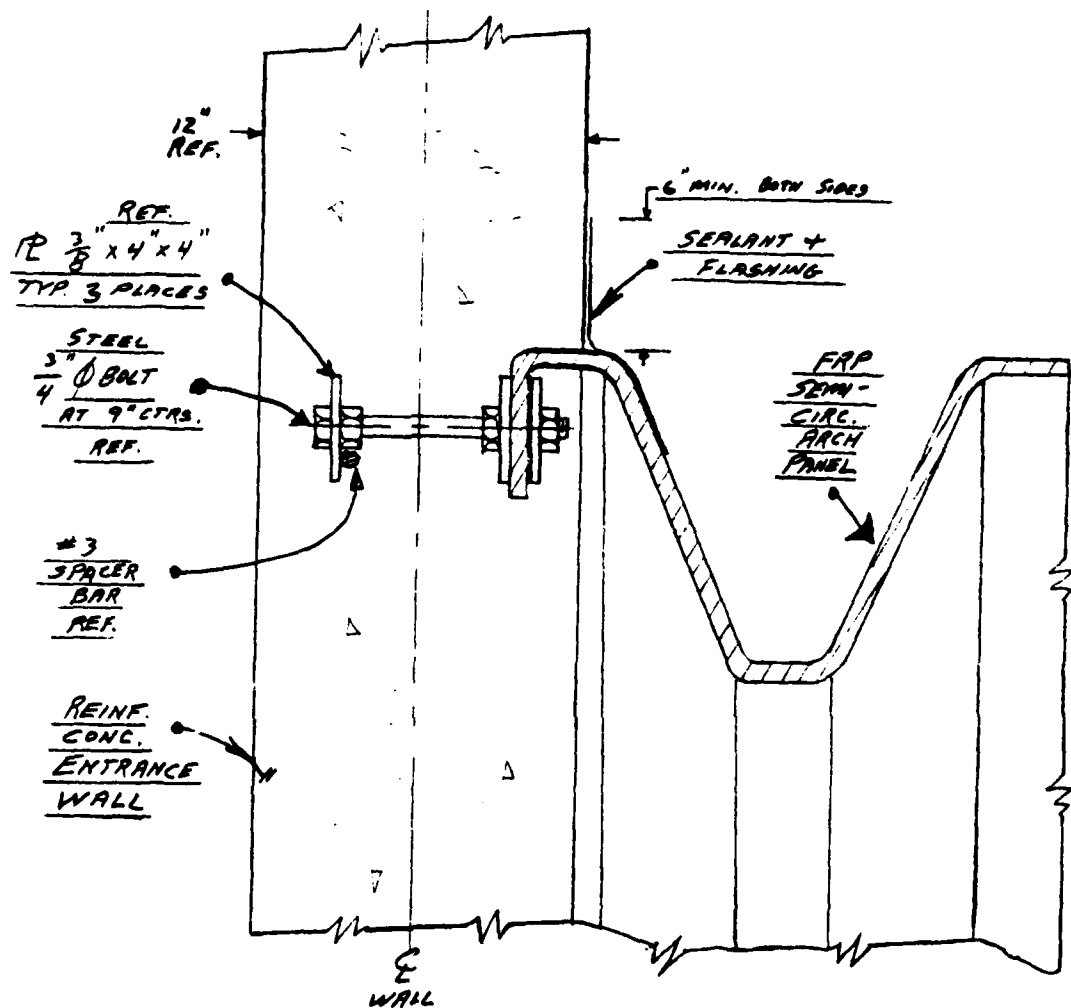
FIGURE 5.9 CONCRETE END WALL/FRP ARCH PANEL EDGE CONNECTION (ENTRANCE)

(SH. 1 OF 2)

STEEL
PL 3/8" x 4" x 4"
TYP. 2 PLACES
REF.

STEEL
3/4" φ x 2'-0" ANCHOR BOLTS AT 9" CTRS.
REF.

SEALANT +
FLASHING

FRP
SEMI-
CIRC.
ARCH
PANEL

#3
SPACER
BAR
REF.

9"
REF.

2"
REF.

REINF.
CONC.
REAR
WALL

5"
REF.

12"
REF.

CE
WALL
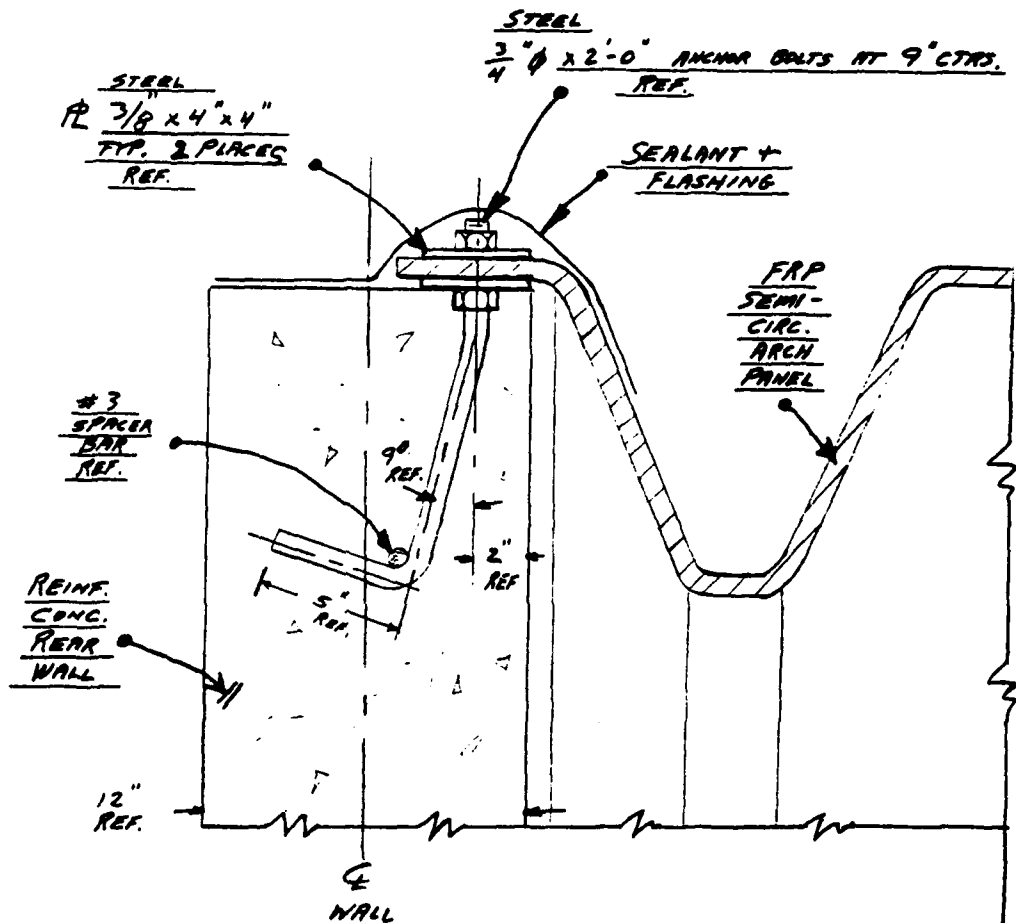
REF. DEPT. OF THE ARMY
DRAWING NO.
33-15-73 SHEET 4 OF 9
DETAIL SECTION A

SECTIONAL
ELEVATION VIEW

FIGURE 5.9 (SH. 2 OF 2)

CHAPTER 6

STRUCTURAL ANALYSES

6.1 CONCEPTUAL DESIGN ANALYSES

During the FRP magazine conceptual design studies, structural analyses were performed using design equations provided in references 6, 7, and 8 for long span metal culverts and FRP pipe along with elastic stability equations from reference 9.

Upon selection of a concept for development of a detail FRP magazine design, more extensive analyses were employed along with the MRI-STARDYNE computer program (Reference 10). This computer code was used with three increasingly exact structural models: an arch-beam element model; an arch-plate element model; an arch and end wall-plate element model.

6.2 ARCH-BEAM ELEMENT MODEL

This first structural model was used to represent the FRP arch panels as two-dimensional beam elements having cross-sectional properties of an 18 inch width of the squared-vee cross-section.

A 90 degree arc segment of the semi-circular arch panels was modelled with symmetry boundary conditions at the crown. Sixteen beam elements were used along the 90 degree arc.

Horizontal and vertical loads due to the magazine earth cover, during and after construction, were applied at uniform intervals over its surface.

This model was used primarily to:

a) Establish and verify the developed magazine soil load distribution.

b) Evaluate the effects of arch panel foundation soil springs.

c) Establish arch panel major section properties required along the arch radius.

6.2.1 SOIL LOAD DISTRIBUTION

The loadings applied to the magazine were the soil weight directly above the shell and the soil weight beyond the arch footing as indicated in Reference 6. The vertical pressure on the shell due to the over-burden was taken as a simple function of the soil depth. The effect of the soil beyond the arch footing was determined as a function of the embankment height and the angle of inclination of the arch surface per table 10-1 of Reference 11. The weight of this soil beyond the arch footing, was accounted for by considering the pressure exerted by a soil wedge extending upward from the footing at a vertical angle of inclination. The development of the soil load distribution and its verification with Reference 6 data are included in Appendix A.

6.2.2 FOUNDATION SOIL SPRINGS

Computer runs were made with the arch foundation fixed in the soil and also with attached springs representing soil stiffnesses. Arch panel applied stresses were found to be somewhat higher with fixed foundations. To ensure realistic modeling of the arch, horizontal, vertical and rotational foundation soil springs were determined per equations 11 and 12 of Ref. 12 and employed for all subsequent analyses.

6.2.3 SECTION PROPERTIES

Several analyses were performed to evaluate panel section properties required with the arch panel rigidly attached to the foundation and with soil springs connected from the foundation to ground. Increased FRP arch panel thickness was shown to be necessary directly adjacent to the foundation as shown in Figure 6.1.

6.3 ARCH-PLATE ELEMENT MODEL

The second structural model used was three-dimensional. A 90 degree arc length and 18" wide strip of the arch was employed. The panel squared-vee cross section was represented by triangular sandwich plate elements at the sloped surfaces of the panel cross section and by solid

quadrilateral plate elements at the horizontal surfaces.

This model included: arch panel top end joint sections; arch panel reinforcement at the foundation interface and foundation soil springs. A computer plot of the model is shown in Fig. 6.2. A thickness of 0.5 inch was used for the quadrilateral elements. A 0.5 inch thick core with 0.125 inch thick skins was used for the triangular elements. Two rows of elements at the base had increased thicknesses. Elements at the crown had a thickness of 1.0 inch to reflect the joint between the two quarter arc sections. Element mesh was increased in the thinner section at each discontinuity.

The mean radius of the arch was 180 inches and the 90 degree arc was divided into 28 basic rows of elements. At discontinuities, such as at the crown and the reinforcement at the foundation, elements were subdivided to allow for greater stress gradients. The soil loads were calculated based on the 28 rows of elements and applied accordingly. The loads applied to each row of elements were determined using the mean radius of the arch. There were eleven nodes at each row cross section. Applied forces were equally divided among the nodes at each level. Calculated maximum plate element model stresses and allowable FRP material stresses are given below.

Maximum Applied Stress	Location	Allowable Material Stress	Factor of Safety
3,494 PSI Compressive Stress	panel sandwich section	16,000 PSI	4.5
122 PSI Transverse Shear Stress	balsa core	490 PSI	4.0

CONT.

Maximum Applied Stress	Location	Allowable Material Stress	Factor of Safety
3,304 PSI Compressive stress	panel solid section	16,000 PSI	4.8

Allowable FRP material stresses are based on laminate thicknesses previously described, 35% glass content and balsa core with a density of 5 pounds per cubic foot. The gross axial load and bending moment at various cross sections are plotted in Figure 6.3 for comparison with the results of the beam model.

6.4 ARCH AND END WALL-PLATE ELEMENT MODEL

This final structural model of the FRP magazine was developed primarily to evaluate local stresses at the junction of the rear magazine arch and end wall. The longitudinal length of arch model used was based on that length at which local edge effects diminish. The shell length was calculated to be 72 inches. (Reference 13)

Triangular sandwich and solid quadrilateral plate elements were employed as in the arch model described above. The density of the plate element mesh used decreased with the distance from the end wall/arch joint.

The end wall was modeled with plate elements. Soil springs were included at the foundation and at the upper edge of the end wall.

Soil loadings were simultaneously applied to the FRP arch and end wall panels. A computer plot of the model is provided in Figure 6.4.

Longitudinal support of the end wall upper portion, provided by backfill, was found to be adequate. Longitudinal loading and displacement of the arch panels were found to be insignificant.

The opposing sloped surfaces of the FRP panel vee-cross-section were found to provide inherent longitudinal equilibrium.

56

Local stresses at adhesive joints between the end wall and adjacent edge of the arch panel, and those between adjacent arch panel edges, were found to be well within the structural adhesive shear and peel strengths.

This final large structural model of the magazine used with the MRI-STARDYNE program provided a very detailed analysis of stresses and displacements throughout the structure. This analysis was considered to provide substantial verification of the adequacy of the design developed for the applied soil loadings.

6.5 STABILITY

The overall stability of the FRP arch was determined considering it to be an elastic curved panel with fixed edges and loaded by uniform radial pressures. The allowable applied pressure was conservatively determined per Reference 14 to be 24 PSI. (The maximum external pressure on the arch due to the earth cover occurs at the base and is approx. 14 PSI.)

FRP panel local and overall stability under axial loadings were evaluated, with data provided in Reference 15, and found to be adequate.

In all analyses performed, a reduced FRP modulus of elasticity $(1 \times 10^6$ PSI) was employed to account for long term properties and elevated temperature.

6.6 SERVICE TEMPERATURE RANGE

FRP laminates constructed with polyester resins are indicated per Reference 16, Table 1, and material supplier's data to have little loss of strength over an operating temperature range of -40 to +130 degrees F.

6.7 CREEP

Data provided in Reference 17 indicates that short and long term creep are not significant design considerations with properly fabricated FRP panels having reinforcement oriented in the direction of the applied loads.

Little long term creep data is available for fiberglass reinforced

57

polyester resins. General information on creep of FRP laminates indicates that strains may increase about 20 to 30% with long term application of stress. This is equivalent to a modulus of elasticity for long term load of about 0.70 times that for short term loads (Ref. 18)
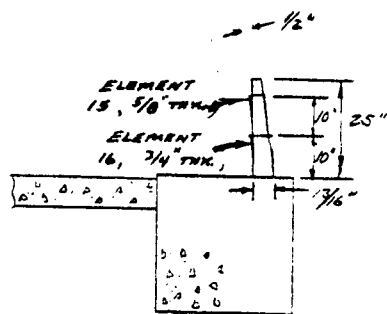
SOLID PORTIONS
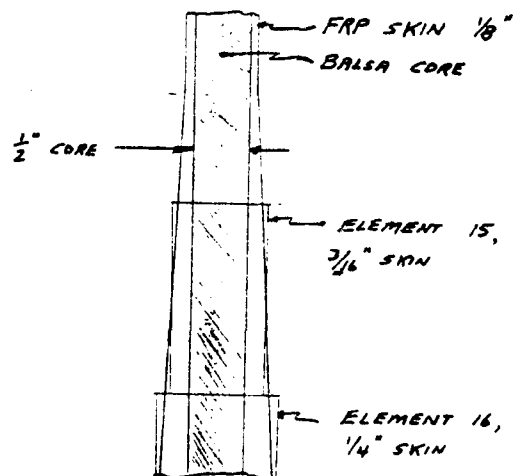
SANDWICH PORTIONS

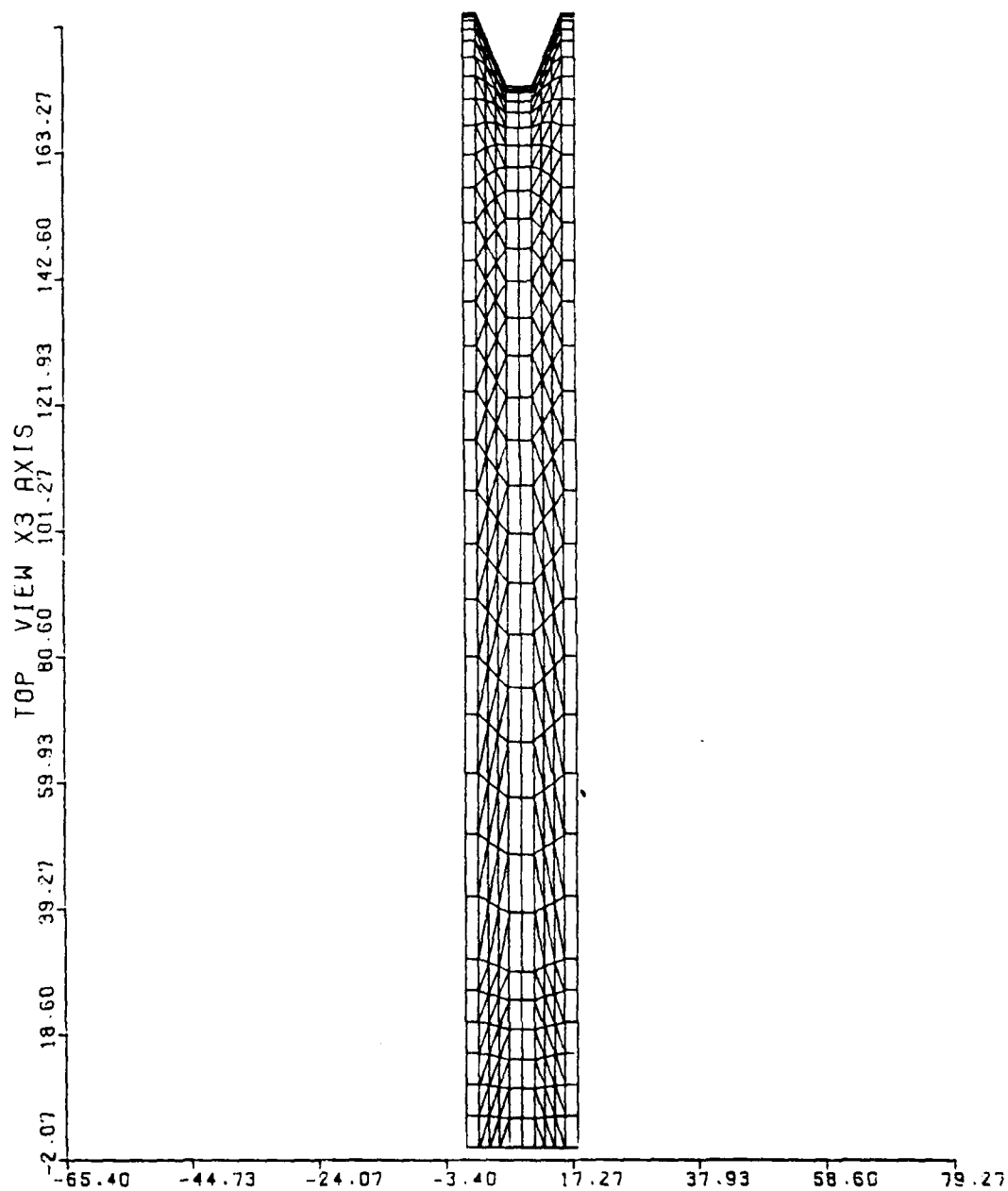FIGURE 6.1   ARCH PANEL THICKNESS AT FOUNDATION

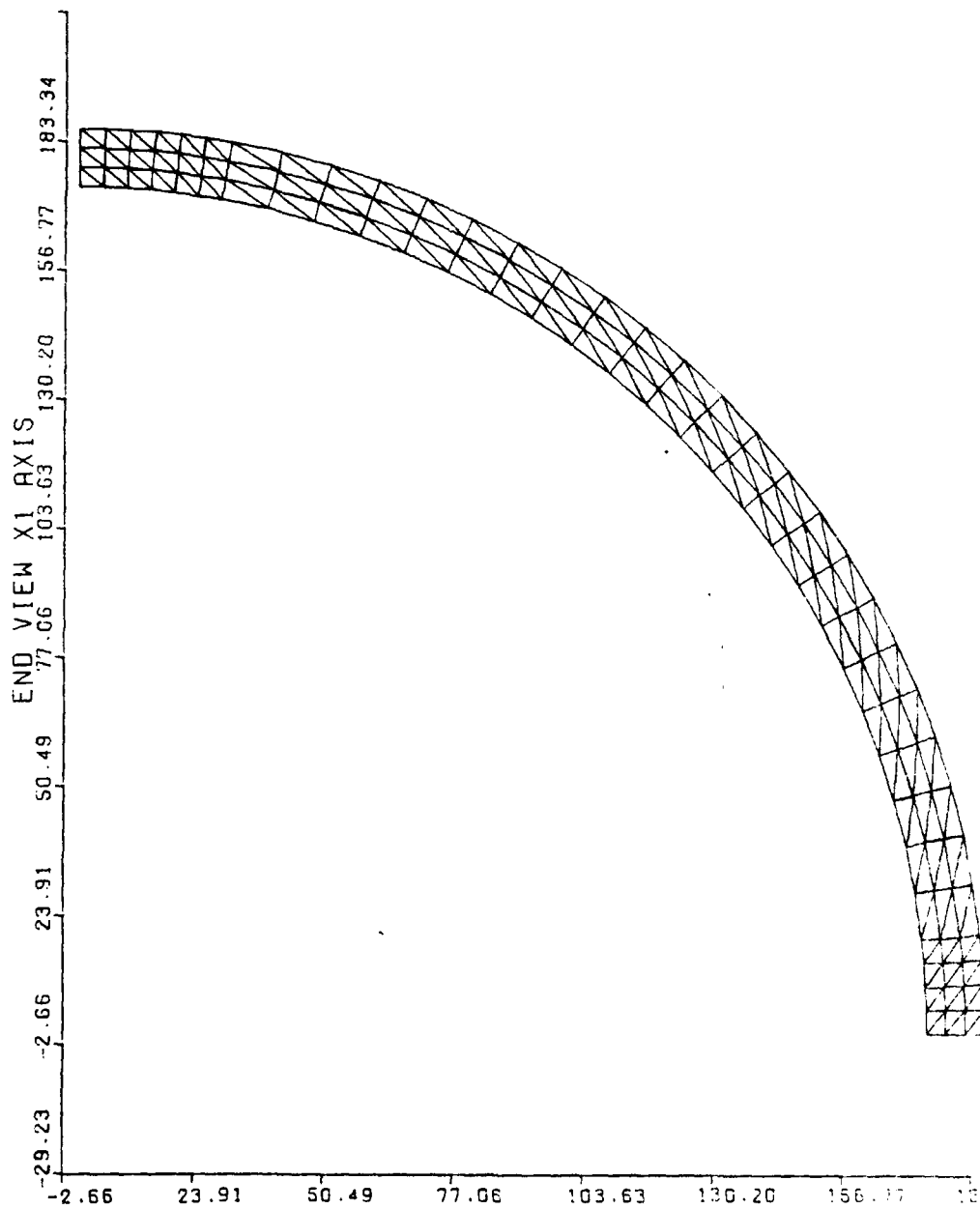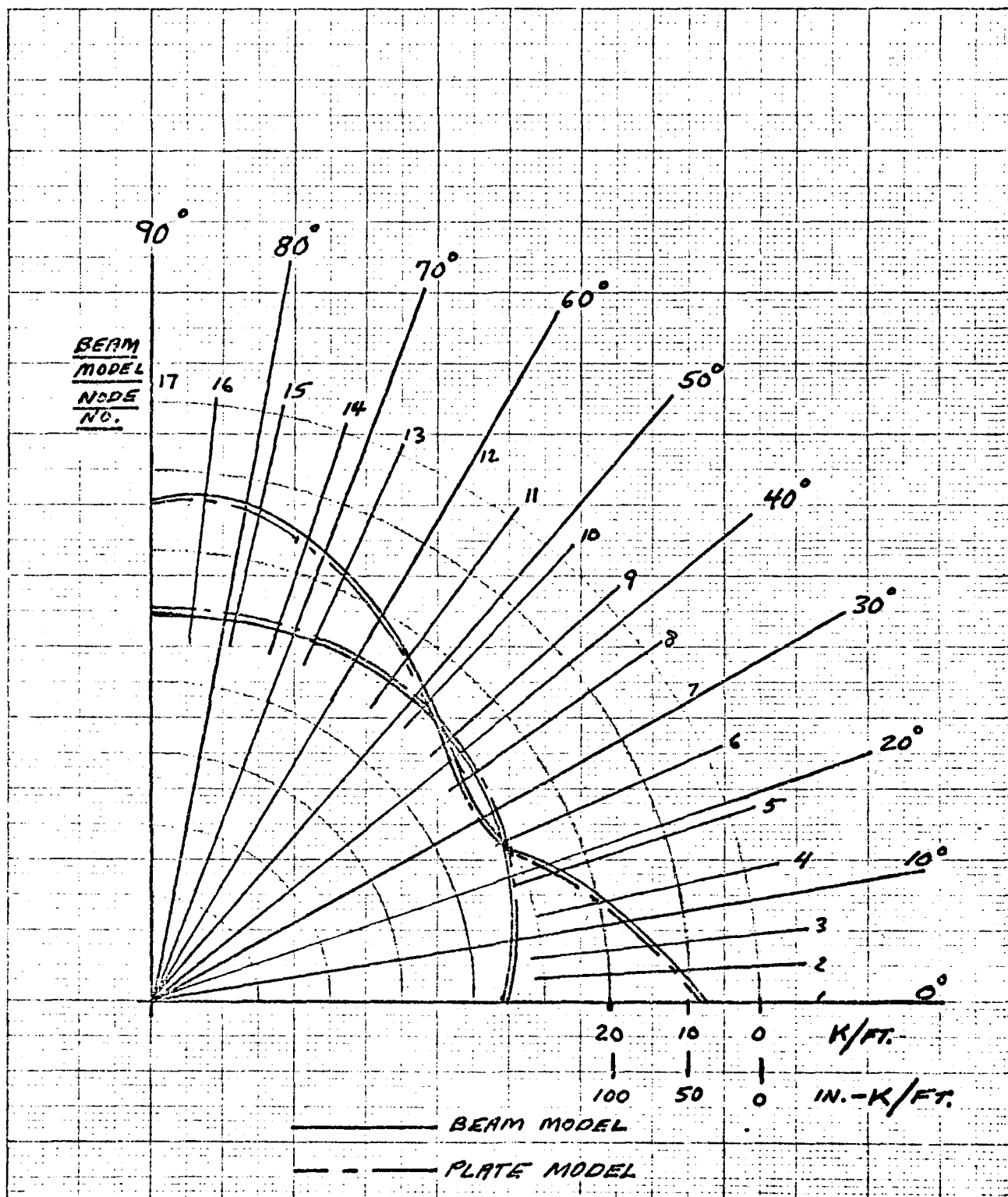FIGURE 6.2 ARCH-PLATE ELEMENT MODEL (SH. 1 of 2)

FIGURE 6.2 (SH. 2 of 2)

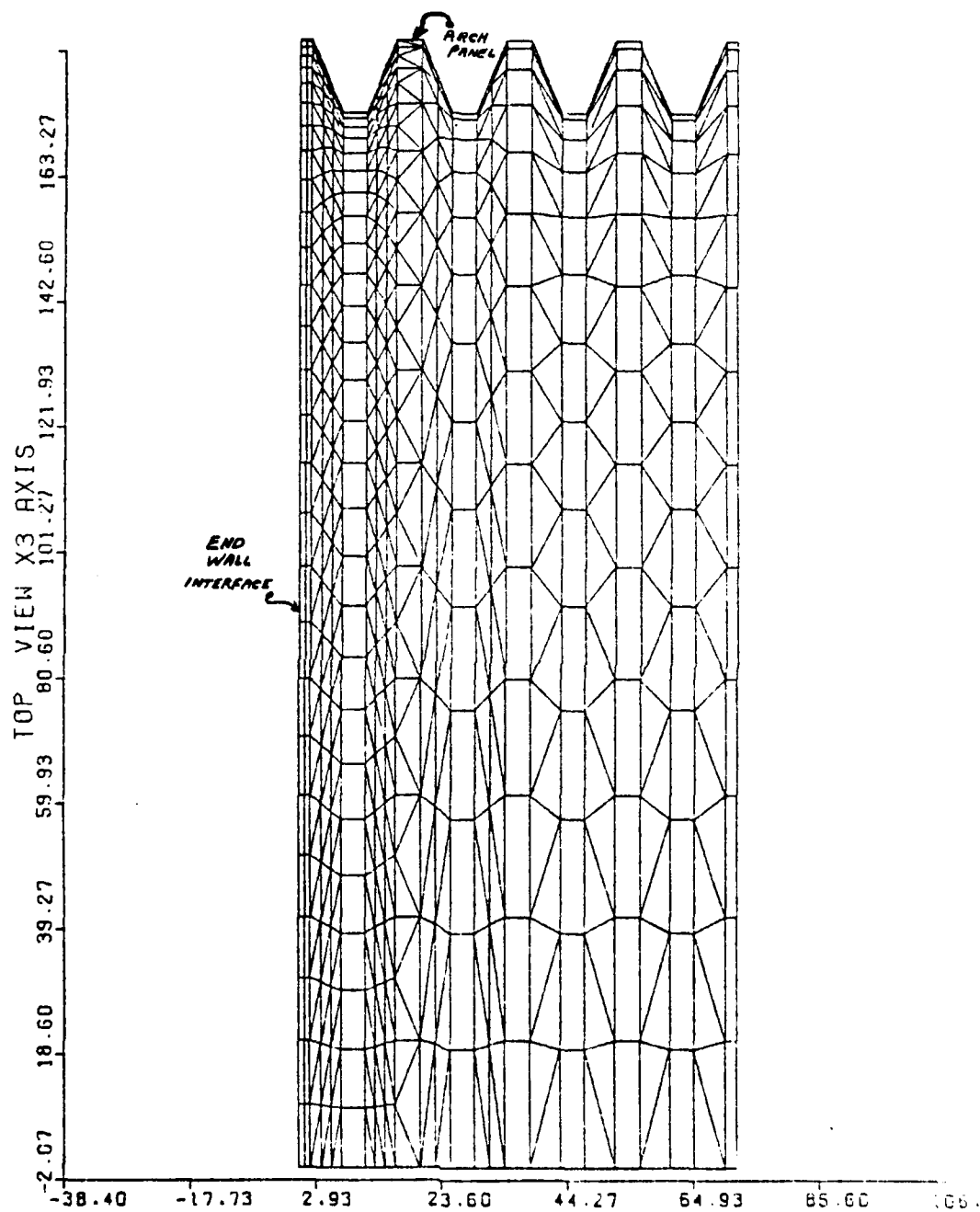FIGURE 6.3   ARCH-AXIAL AND BENDING LOADS

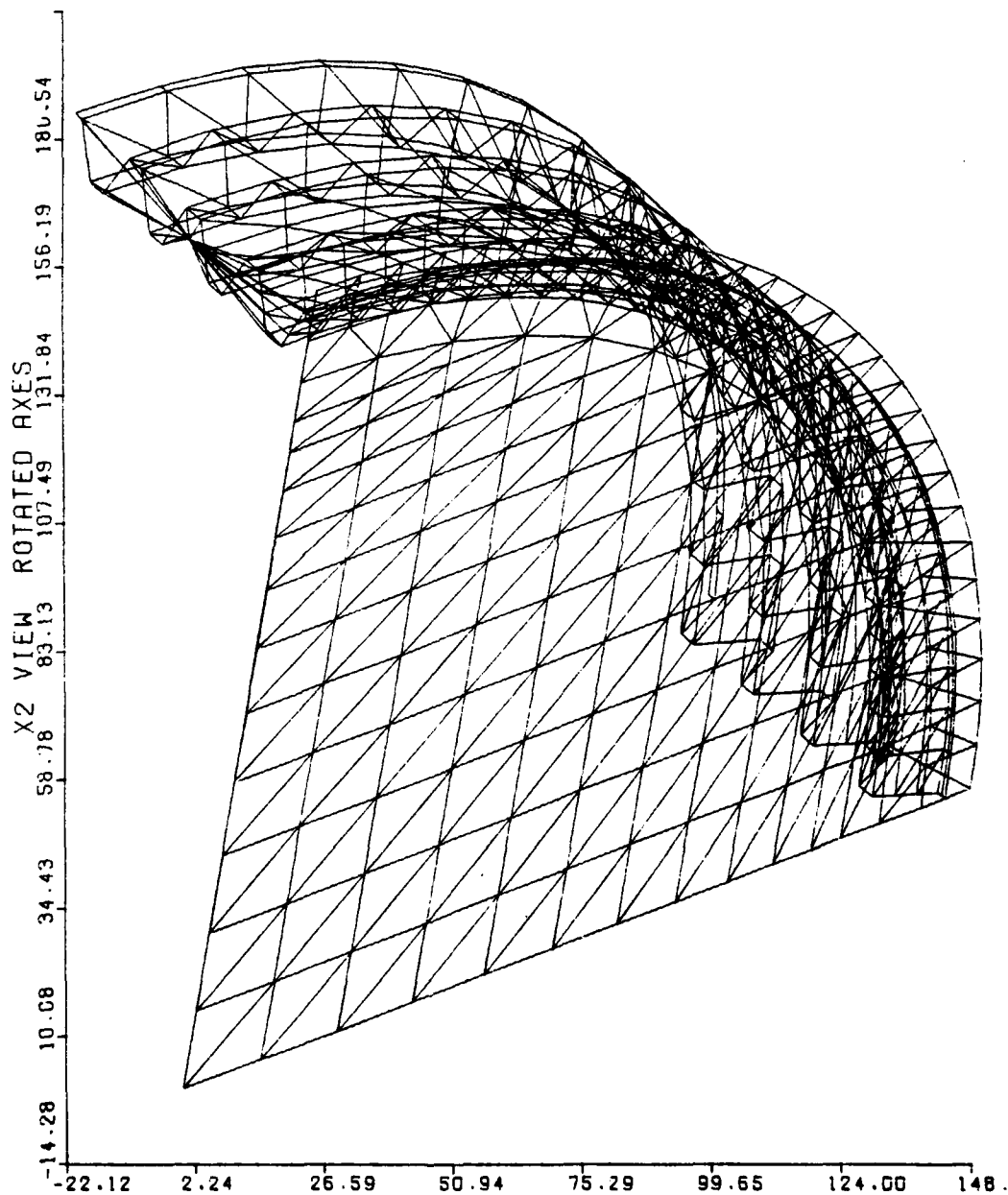FIGURE 6.4   ARCH AND END WALL-PLATE ELEMENT MODEL (SH.1 of 2)

FIGURE 6.4 (SH. 2 of 2)

CHAPTER 7

CONSTRUCTION COSTS

Estimated manufacturing and field installation costs for the
FRP magazine arch and end walls were developed as shown in Table-4 based
on early 1980 prices.

For comparison purposes, manufacturing and field installation
costs of the present magazine steel oval arch structure per Corps of
Engrs. dwg. 33-15-73 were also developed as shown in Table-5 with early
1980 cost data.

Some additional factors which should be considered in cost comparisons for specific magazine sites are:

a) Material transportation costs.
b) Required service life.
c) corrosiveness of available backfill.
d) Cathodic protection system operation costs.
e) Anticipated life cycle maintenance costs.

TABLE – 4

ESTIMATED CONSTRUCTION COST

FRP Arch and End Walls

1. ARCH

    a) Semi-circ. pnls. 15'R, 90° arc, 7½ wide,
                    8 ea. r.h. and l.h.
        60' magazine length x $ 755.63/ft ———————————— $ <u>45,338</u>

    b) joint wedge blocks,
        adhesive/sealer,
        reactive adh. ————————————————————————— $ <u>295</u>

    c) Inst. labor – foreman 24 hrs @ 18.50
                  laborers 48 hrs @ 15.70 ———————— $ <u>1,198</u>
            (Ref. 19)

    d) $18,000 mold cost dist. over 10 magazines
                  at 1800 each ————————————————— $ <u>1,800</u>

                                        subtotal $ <u>48631</u>

———

2. REAR FRP WALL ABOVE FOOTING

    a) Vee wall pnls. 402 s.f. x $15/s.f. ——————— $ <u>6,030</u>

    b) Joint materials
        reactive adh. and wedge blocks ————————— $ <u>120</u>

    c) Inst. labor :
               foreman 8 hrs @ 18.50
               laborers 16 hrs @ 15.70 ——————— $ <u>399</u>

                                        subtotal $ <u>6549</u>

———

3. FRP ENTRANCE AND WING WALLS

    a) Panels and tie mbrs. 2960 s.f. x $10/s.f. ——— $ <u>29,600</u>

    b) Joint materials (bolts and adh.) ——————————— $ <u>350</u>

    c) Inst. labor :
               foreman 24 hrs. @ 18.50
               laborers 48 hrs. @ 15.70 ——————— $ <u>1,198</u>

d) FRP door and track installed ————————————— $ 625

subtotal $ 31773

4. TOTAL ESTIMATED COST ———————————————————— $ 86953

TABLE - 5

ESTIMATED CONSTRUCTION COST

Present Steel Plate Arch and Reinforced Concrete End Walls:
(Per DWG. 33-15-73)

1. ARCH
   a) Steel plate arch plates, bolts, sealing strips, anchor
      bolts and channels, (knockdown) :

      60' Magazine length x $400/ft. ————————— $ 24,000
         (Ref. Armco Co. Quote)

   b) Installation Labor:
      $24000 x .4524 = —— ——————————————— $ 10,857

   c) Waterproofing Membrane and Protector Boards:
      $.75/ft.^{2} x 2827 ft.^{2} ————————————— $ 2,120
         (Ref. 19)

                                    subtotal $ 36,977

───

2. REAR REINFORCED CONCRETE WALL ABOVE FOOTING (Ref. 19) :
   a) 13.4 C.Y. x $215/C.Y. Conc. in place ———————— $ 2,881
         (incl. forms and reinf.)

   b) Arch anchor bolts, $4.31/s.f. x 612.5 s.f. ——— $ 2,640
      and finishing.

   c) Waterproofing, $.75/s.f. x 637.5 s.f. ———————— $ 478

                                    subtotal $ 5,999

───

3. REINFORCED CONCRETE ENTRANCE WALL ABOVE FOOTING AND RETAINING
                 WALLS AND FOOTINGS
   a) 93.3 C.Y. x $125/C.Y. conc. ———————————— $ 20,060
      in place incl. forms and reinf.

   b) Arch anch. bolts $4.31/s.f. x 1138 s.f. ——— $ 4,905
      and finishing

c) Sliding steel $145/s.f. x 76 s.f. ———————— $ 11,020
   door and frame
        (Galv.)

                                        subtotal $ 35,985

_____

4. CATHODIC PROTECTION SYSTEM
    Estimated —————————————————————————————— $ 5,000

_____

5. TOTAL ESTIMATED COST —————————————————————— $ 83,961

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 CONCLUSIONS

A corrosion resistant FRP, earth-covered ammunition storage magazine design was developed and shown to be highly feasible.

Based on magazine total life-cycle cost, and early 1980 manufacturing and installation cost data, the cost of the FRP magazine is expected to be less than that of the present steel plate and concrete magazine.

Other major advantages of the FRP magazine were determined to be:

a) Reduced material handling and shipping weight.
b) Reduced field erection time required.
c) Reduced maintenance.
d) Increased service life.

8.2 RECOMMENDATIONS

It is recommended that a prototype FRP, earth-covered ammunition storage magazine be constructed.

Also, it is recommended that the prototype structure be constructed so as to demonstrate:

a) Structural design.
b) Manufacturing, shipping and field erection.
c) Construction cost.

APPENDIX A

## DERIVATION AND VERIFICATION OF SOIL LOADING EQUATIONS

Equations for the soil load distribution on the FRP magazine arch were derived for use with the structural model developed and the MRI STARDYNE computer program.

In Reference 6, the results of numerous non-linear finite element analyses of various combinations of culverts and backfills are provided in empirical formulas and graphs. These formulas and graphs were used to verify the soil load distribution equations derived.

The soil loading on arch beam elements 1-8, shown in Fig. A-1, was considered to include the additional weight of the soil beyond the arch span. The loading on arch elements 9-16 was considered to be only that of the soil plug directly above.

The loading on elements 1-8 was determined assuming that each element was loaded by the adjacent inclined soil column as shown in Fig. A-1.

The forces on a typical element, due to the inclined column of soil, were determined by the equations below.
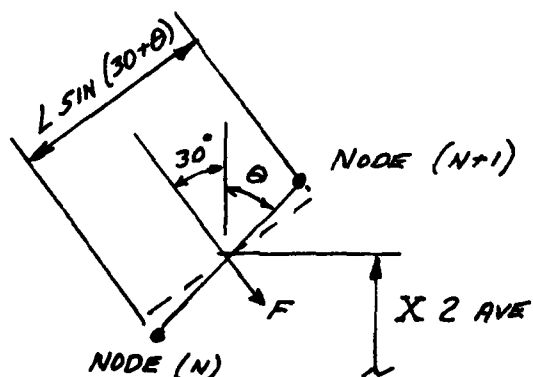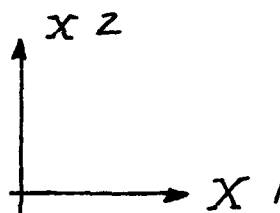
$\theta = Tan^{-1} (\Delta X1 / \Delta X2)$

$L = MEMBER\ LENGTH$

$\gamma = SOIL\ DENSITY = 120\ PCF$

$F = W\ COS\ 30°$

$$W = \gamma \; \frac{\left[(15+2)(12) - X2 \, AVE\right]}{\cos 30°} \; L \; SIN\,(30+\theta)\,(18)$$

$$F = \gamma \,(204 - X2 \, AVE)\, L \,(18)\; SIN\,(30+\theta)$$

$$F_V = \gamma \,(204 - X2 \, AVE)\, L \,(18)\; SIN\,(30+\theta)\cos 30°$$

$$F_H = \gamma \,(204 - X2 \, AVE)\, L \,(18)\; SIN\,(30+\theta)\; SIN\,30°$$

The vertical forces on elements 9–16 are a function only of the plug of earth directly above the element. The horizontal pressure on each of these elements were determined using an "at rest" coefficient of lateral pressure equal to 0.5 (Ref. 11).

$$F_V = \gamma \,(204 - X2 \, AVE)\,(\Delta X1)\,(18)$$

$$F_H = 0.5\,\gamma \,(204 - X2 \, AVE)\,(\Delta X2)\,(18)$$
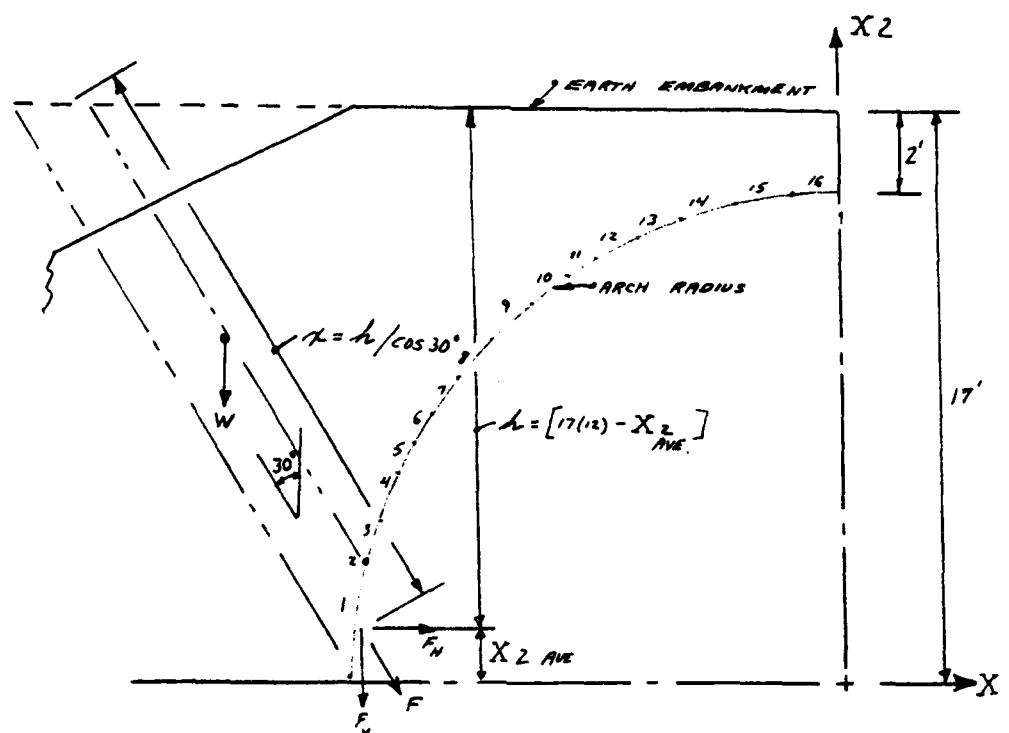
F_v and F_H — Vertical and Horizontal Components of the Force
at the Center of each Element

X_i — Global Coordinate System of the Model

Vertical Angle of Inclination = $45 - \phi/2 = 30°$

ELEMENT LOADING
FIG. A-1

73

The above loads were applied to the arch beam element model described previously with arch ends simply supported as in Ref 6. The maximum axial stress was 1968 PSI and the maximum axial force was 20,851 lbs. The corresponding data from an analysis performed with data from Ref. 6 were:

Maximum Axial Force =: 23,250 lbs.

Maximum Axial Stress = 2210 PSI

The maximum bending moment was found to be 106,156 in.-lbs. and the maximum bending stress was 2986 PSI. The comparable values using Ref. 6 were:

Maximum Bending Moment = 58,860 in.-lbs.

Maximum Bending Stress = 1660 PSI

The bending stress using the model is approximately 1.8 times that obtained analytically. The error in the stress due to axial compression was approximately 10%. The bending stress obtained from the model was conservative, and the axial stress was slightly unconservative compared to results using Ref. 6. However the maximum combined stress from model was greater than the sum of the maxima using Ref. 6.

MAX = 4150 PSI   MAX = 3870 PSI
model   ref.

A plot of the arch bending moment and axial force are provided in Fig. 6.3. A comparison of the plots in Fig. 6.3 with similar plots in Ref. 6 indicates that the form of the curves is essentially the same. Maximums occur at approximately the same relative locations (i.e. maximum bending moment at a point 30 degrees up from base and maximum axial force at the base).

Thus, the method of calculating the applied loads described above was considered acceptable and used in subsequent computer analyses.

REFERENCES

1. Frank J. Heger, et al; "Design of Plastic Structural Components"; 1979, Page 431; Journal of the Technical Councils of ASCE; Proceedings of the ASCE, Vol. 105, No. TC2, ASCE, Ny,Ny; Unclassified.

2. Pipeline Sub-committee; "Reinforced Thermosetting Resin Pipe" March 1979, Page 167; Transportation Engineering Journal; ASCE, NY, NY; Unclassified.

3. "Guide to Corrosion Resistance of Hetron and Aropol Polyester and Furan Resin Laminates"; 1978; Bulletin No. 1407, Ashland Chemical Co., Resin and Plastics Div., Columbus, OH.; Unclassified.

4. "Hand Lay-up Spray-up Guide"; 1979; Publication No. 5-PL-9342 Owens-Corning Fiberglas Corp. Toledo, OH.; Unclassified.

5. "Specifications for Construction of St. Louis Area Support Center, Ammo Storage Magazines, Granite City, Ill.; Serial No. DACA 45-80-B-0091; Mar 1980; U.S. Army Engr. Dist., Omaha, Nebraska; Unclassified.

6. James M. Duncan; "Behavior and Design of Long Span Metal Culverts"; March 1979, Pages 399-418; Journal of the Geotechnical Division, ASCE, New York, N.Y., Proceedings Paper 14429; Unclassified.

7. B. Jay Schrock; "Installation of Fiberglass Pipe"; Nov. 1978; Pages 835-846; Transportation Engineering Journal, ASCE, NY, NY; Unclassified.

8. Simpson Gumpertz and Heger Inc; "Structural Plastics Design Manual"; 1979; FHWA-TS-79-203; Sponsored by U.S. Dept. of Transportation, Dept. of Housing and Urban Development and industrial organizations; U.S. Govt. Printing Office Stock Number 023-000-00495-0; Unclassified.

9. S. Timoshenko; Theory of Elastic Stability"; 1936; McGraw-Hill Book Co., New York, NY; Unclassified.

10. STARDYNE Computer Code; "Static and Dynamic Structural Analysis Systems" User Information Manual, Control Data Corporation, Publication No. 79900; Unclassified.

11. Gregory P. Tschebotarioff; "Foundations, Retaining and Earth Structures"; 1973; McGraw-Hill Book Co., New York, N.Y.; Unclassified.

12. R.V. Whitman, et al; "Design Procedures for Dynamically Loaded Foundations"; Nov 1967; Pages 169-193; Journal of the Soil Mechanics and Foundations Div., ASCE, New York, NY; Unclassified.

13. S. Timoshenko; "Theory of Plates and Shells"; 1940; Engineering Societies Monographs, McGraw-Hill Book Co. New York, NY; Unclassified.

14. Raymond J. Roark; "Formulas for Stress and Strain"; Fourth Edition; McGraw-Hill Book Co., New York, NY; Unclassified.

15. "Structural Sandwich Composites", Military Handbook, MIL-HDBK-23A; Dec 1968; Dept of Defense, Washington, DC; Unclassified.

16. "High Temperature Properties of Corrosion Resistant FRP"; Feb. 29,1977; Paper presented to: 32nd Annual Conference and Exhibit, Reinforced Plastics/Composites Institute, The Society of the Plastics Industry Inc., Unclassified.

17. F.P. Belyankin, et al; "Strength and Deformability of Fiberglass Reinforced Plastics Subjected to Biaxial Compression"; Charlottesville, VA; NTIS AD-A008517.

18. Frank J. Heger; "Design of FRP Fluid Storage Vessels"; March 1970, Pages 2465-2499; Journal of the Structural Division; ASCE; New York, N.Y. Unclassified.

19. "1980 Building Construction Cost Data"; R.S. Means Co. Inc., Kingston MA.

E
ED